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THE VOLCANOES OF THE KULA BASIN IN LYDIA

Inaugural Dissertation

FOR THE A...

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INTRODUCTION.

IN the course of the writer's studies at the University of Leipzig during the winter semester of 1891–92, the volcanic district in Asia Minor known to the ancients under the name of the Katakekaumene in Lydia was spoken of by Prof. Dr. Zirkel as promising a good field for petrographical work, and it was decided to visit it in the spring. Accordingly, after a two months' stay in Greece, the writer was able, in April, to pass over into Asia Minor, where nearly two weeks were spent in visiting, with friends, sites of archæological interest. Unfortunately, an important matter unexpectedly called the writer away, leaving only eight days for an examination of the region named above. The shortness of the time is regretted, but it is hoped to visit the place again in the spring of 1894, when a map will be drawn, and as complete an exploration of the whole region as possible be made. In the meanwhile this paper will give a short preliminary sketch of part of the district, and the results of a petrographical examination of the rocks collected, undertaken in the Mineralogical Institute of the University of Leipzig, under the guidance of Geheimrath Prof. Dr. Zirkel, to whom the writer desires to return his warmest thanks and to express his sense of the great obligations he is under for the constant and invaluable aid and advice and the never-failing kindness shown him.

THE VOLCANOES OF THE KULA BASIN IN LYDIA.

GENERAL DESCRIPTION.

THE chief town of the district,* and the one that the writer made his headquarters, is Kula,† the seat of a large carpet industry a place with 12,000 inhabitants, of whom 8500 are Turks, and the rest Greeks. It is situated in 38° 33′ N. Lat. and 28° 42′ E. Long., in the eastern part of the vilayet (province) of Aidin, or what was anciently called Lydia, some 125 kilometres E. by N. of Smyrna, in a straight line. It is reached by travelling by rail to Ala Shehir (ancient Philadelphia), a trip of 169 kil. (6½ hours), where one spends the night. From Ala Shehir one drives over a good road across the Konŭrja Mountains, and reaches Kula in about 5 hours. As the only regular accommodation for travellers is a very dirty, noisy, and public khan, one must either bring letters to some of the inhabitants, or trust to someone's hospitality for a lodging. The writer was most kindly received and courteously treated by a Greek named Haji Moisé, who several times acted as guide to various places of interest, and to whom the writer wishes to return his thanks. It may be remarked that a knowledge of modern Greek or

* As some Turkish topographical words will be used in the course of this and other papers, the following short vocabulary will be found of use: *Bŭnnár* = Spring. *Chaï* = River. *Dag* = Mountain. *Göl* = Lake. *Hissár* = Castle. *Kalé* = Fortress. *Köi* = Village. *Köprü* = Bridge. *Shehir* = City. *Sŭ* = Water, Brook. *Tash* = Rock. *Tepé* = Hill.

The plural is formed by adding the syllable *lar* or *ler*, according as the vowel of the word is strong or weak. The accent of Turkish words falls as a rule on the last syllable.

† The name Kula (also written Koulah) is derived from the Turkish *Külé* = a tower. The Byzantine fortress of Opsikion stood on this site. Cf. Ramsay, Hist. Geog. As. Min. p. 123.

Turkish is almost indispensable, though one can get along with a dragoman.

Ancient History.—The extant historical notices of the region are extremely scanty, being confined practically to three writers. Strabo (born *ca.* 54 B.C.), in his famous geography, is the first to mention it. He speaks as follows:* "After these (Mysia and Philadelphia) is the country called Katakekaumene (Burnt Country), 500 stadia † in length and 400 in breadth, which belongs to either Mysia or Mæonia, for it is ascribed to both; . . . entirely bare of vegetation, except for the vine which produces the Katakekaumene wine, which is not inferior to any other of the famous wines.‡ The appearance of the plains is ashy, and of the mountainous part stony and black, as if from a conflagration.§ Some represent this as having happened from thunderbolts and lightning strokes, and do not hesitate to make it the scene of the fable of Typhon. . . . But it is unreasonable to suppose that so large a district was all at once consumed by lightning and thunderbolts; it is more natural to think that the effect was produced by fire generated in the soil, the source of which is now exhausted. And three pits are shown, which they call blow-holes (φῦσαι), distant 40 stadia from each other. Rough hills lie over these, which have probably been heaped together from the glowing masses blown up. . . . "

Vitruvius (de Archit. II. 6), in speaking of cements and mortar, says that this region and Ætna are the two whence is obtained suitable pumice, or volcanic ashes, for mixing with lime. He quotes the presence of hot springs as evidence of their volcanic origin.

From Metaphrastes,‖ a late Byzantine writer, we learn that the district was called Decapolis, and he speaks of it as having been burned with fire.

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* Strabo, XIII, 4, 11.

† The Stadion was about one eighth of an English mile. As Hamilton says, Strabo has evidently overrated the extent of the district, its real length being about 18 miles, and its breadth 7 or 8.

‡ Pliny (N. H. xiv. 75) mentions this wine.

§ The modern Turks recognize the igneous origin of these lava beds in their name for them, *Janyk Tash* = Burnt Rock.

‖ Acta Pionii, in Acta Sanctorum, Febr. 1, p. 48. "Vos Decapolim, Lydiæ regionem, igne combustam, videtis." Cf. Ramsay, *op. cit.* pp 123, 132, 432.

None of these writers speak of volcanic eruptions as taking place in their day, though Strabo evidently thinks that such eruptions have produced the three principal volcanoes. He speaks in another place of Philadelphia as being "full of earthquakes," so much so that walls were overthrown, great damage done, and few of the inhabitants lived in the city. We may, however, take it for granted that there has been no eruption in historical times, though the history of Asia Minor is so imperfect that the record of such an occurrence may not have come down to us. With the exception of a few hot springs, to be mentioned later, there are no indications of volcanic action going on at present, and I could hear of no traditions to the effect of an eruption having been seen by the present inhabitants or their ancestors.

Modern Descriptions.—The chief modern writers who have described the region from a geological point of view are W. J. Hamilton,* H. E. Strickland,† P. de Tchihatcheff,‡ and C. Texier.§ The two former in 1836, and the first alone in 1837, travelled across the region and described it. The third, some years later, also visited it, but chiefly confines himself to quoting the other two and confirming their observations. Texier's account is also based chiefly on Hamilton's work, and partially on a personal visit to the Kula Basin. The western portion he describes by hearsay. It is readable but short, and, as he was not a geologist, at fault in some particulars. As the two earlier writers give a very good idea of the plan and structure of the region, we cannot do better than make a few quotations from their joint paper:

"The tertiary deposits in this basin of the Katakekaumene consist of horizontal beds of white limestone passing downwards (in the northern part of the basin) into volcanic tufa. The limestones have been deeply denuded by the Hermus (Gediz Chaï) and its tributaries, and now form a series of lofty plateaux. . . .

"The Catacecaumene is described . . . as a tertiary lacustrine basin, surrounded by hills of schistose rocks. It is drained by

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* Hamilton, Researches in Asia Minor, Pontus and Armenia. London, 1842. I. 136–140 and II. 130–150.

† Hamilton and Strickland, On the Geology of the Western Part of Asia Minor. Trans. Geol. Soc., 2d Ser., VI. 81.

‡ Tchihatcheff, Asie Mineure. Pt. IV. Géologie. Paris, 1867. I. 7. 211 ff.

§ Texier, Asie Mineure. Paris, 1882. pp. 272–275.

the Hermus, which escapes at Adalá through a narrow gorge in the schistose formation, the closing of which to a sufficient height would again convert the upper country into a lake. Numerous volcanic eruptions have taken place among the older rocks, which formed the southern margin of the basin; and streams of lava, flowing from these foci, have overspread the lacustrine deposits.

"The outbursts of volcanic matter appear to be referable to three great periods. How long may have been their duration, or how long the interval of repose between each, is buried in the tomb of time. All that we can now assert is that long intervals must have passed between each eruption; and that the latest eruption occurred antecedently to the commencement of traditional or authentic history.

"The oldest series of eruptions took place at a time when the bed of the lake presented a nearly level and unbroken surface, and before the first commencement of the excavation of the present valleys; for the basaltic rocks of that period invariably form the capping of the vast horizontal plateaux of tertiary lacustrine limestone. . . . The eruptions of the second period were subsequent to the drainage of the lake, and to the excavation of deep valleys in the lacustrine deposits. Those of the third period are still more recent, and are distinguished by their entire identity of character with volcanoes now in action."

As I did not visit any of the first-period basalt sheets, and have no specimens, we will here omit their description. To continue the quotation:

"To the second period of volcanic action we refer the numerous conical hills of scoriæ and ashes which cover the schistose ridges on the south of the lacustrine formation. The range of mica schist and marble, which runs from east to west on the south of Koola, sends off three nearly parallel ridges towards the north, and may therefore be compared to the letter E. The volcanic cones of the second period are scattered along this principal ridge and its three lateral branches,* and many streams of lava may be traced flowing from them, and descending the valleys of denudation in the lacustrine formation towards the Hermus.

* There are, as seen on the map, a number of exceptions to this rule, where second-period cones have been formed in the basin between the schistose ridges.

"The volcanic products of this period are distinguished by the smoothness of their outlinés, and by the vegetation which clothes their surfaces. The cones of scoriæ are all low and flat, rising at an angle of about 20°; their craters have either disappeared, or are marked only by small central depressions, and all their asperities seem to have been smoothed down by time. The scoriæ which form them are sufficiently decomposed to admit of cultivation, and they are almost invariably covered with vineyards, producing the Catacecaumene wine, celebrated from the time of Strabo to the present day. The streams of lava which have flowed from them are level on the surface and covered with turf.

"The volcanic cones of both the second and third periods have been poured forth since the excavation of the valleys in the lacustrine formation; but their diversity, in point of age, is marked no less by their order of superposition than by the great difference in their state of preservation. The cones of the third period have all the features of volcanoes now in action. They rise at an angle of 30° or 32°, and the ashes and scoriæ which compose them are so loose as to render the ascent laborious. A few straggling shrubs and plants are the only vegetation they produce; and the lava which has flowed from them is as rugged and barren as the latest product of Ætna or Vesuvius.

"The volcanoes of this third period are only three in number,* and are nearly equal in size. They stand in a nearly straight line from W. by N. to E. by S., and at a distance of about six miles from each other. It is remarkable that each of them rises in the centre of one of the small alluvial plains which alternate with the three schistose ridges before described, therein differing from the cones of the second period, all of which stand upon, or near, those ridges."

The above general description will give the reader a tolerably clear idea of the whole district. The shortness of my stay prevented me from doing more than studying partially the easternmost, or Kula, basin, with one trip to beyond the Gediz Chaï on the north, and another to Gülde on the northwest. Other hindrances were the difficult nature of the ground, want of a map, and the great heat. Some time was also spent in archæological investigations.

* The cone of Kara Tepé must be added to this number, and there are perhaps others farther west.

The Kula Basin.—A more particular description of the Kula Basin may now be given, for which the accompanying sketch map has been drawn.* Cf. Plate I.

The geological structure of this basin is seen in the section (Fig. 1) which runs from Hammamlar to the Konurja Mts. From this it will be seen that the mountain range to the south of Kula, and the rocks underlying the basin itself, are hornblende-schist and mica-schist. The former forms the lower strata and constitutes the greater part of the Konurja Mts. At Azi Köi the strata are almost horizontal, but farther up the southern slope of the ridge (about an hour below the top of the pass) they dip 30° towards the N.W. Near Kula we find mica-schist overlying this in almost horizontal strata, with here and there veins of marble.† This marble is often very white, and can be quarried in large masses,

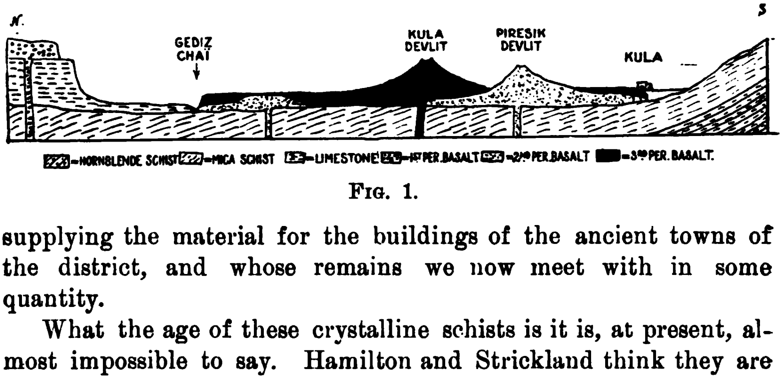

Fig. 1.

supplying the material for the buildings of the ancient towns of the district, and whose remains we now meet with in some quantity.

What the age of these crystalline schists is it is, at present, almost impossible to say. Hamilton and Strickland think they are pre-cretaceous, and "provisionally" refer them "to the primary or transition epoch." Tchihatcheff ‡ also "provisionally" places the mica-schists and allied rocks of Asia Minor in the Devonian or Carboniferous Period. From their geographical proximity and similarity of characteristics, it is possible that they belong to the same age as the great schistose formations of Greece. This, however, is uncertain and we must leave the queston an open one.

* Hamilton and Strickland (*loc. cit.*) give a map of the whole district with some sections, which, however, does not seem to be very accurate. The present map, also, does not pretend to any great accuracy. It has been compiled partly from Hamilton's map and partly from my own notes. Lack of time did not allow of my making a survey.

† Cf. Tchihatcheff, *op. cit.* p. 544.

‡ *Op. cit.* p. 476.

The limestone through which the basalt of the first period poured is called tertiary by Hamilton and Strickland, and there seems no reason for doubting the correctness of this opinion, though no fossils were found in it. That the third and second periods of eruption were post-tertiary there is no doubt whatever, to judge from their fresh state of preservation. While the form of the second-period cones is somewhat degraded, yet the outlines of many of them are still sharp and their craters very distinct, while the third-period cones have apparently suffered hardly at all from atmospheric action. Hamilton and Strickland seem inclined to account for the more denuded state of the second-period cones by supposing them to have been formed by a subaqueous eruption. But they themselves admit the difficulties of this view, and it seems hardly worth while to dwell upon it. The limits and aims of the present paper do not admit of further remarks on the general geology of the region, and we can now turn to the volcanic cones and their lava streams.

Second-Period Cones.—The second-period cones of the Kula Basin are as follows: Southeast of Kula Devlit (the principal third-period volcano of the basin), and joined to it by a ridge of lava, is the large, breached, crater cone of Piresik Devlit,* about 150 m. high, with its open side to the southwest, from which has flowed a lava stream, now covered by the Kula Devlit outpours. This presents all the characteristics of second-period cones mentioned by Hamilton. The outer slope is at an angle of 20°–34°, and the inner slopes of the crater are planted in vines. To the southeast stretch a line of three small cones, Yelé Tepeler (Hills of the Horse's Mane), and to the northeast are also two small cones spoken of later. About three kilometres to the east is Göl Dag (Lake Mountain), a large unbreached crater cone, and beyond this another second-period cone. Two and a half kilometres to the north-northwest of Kula Devlit rises the cone of Böz Tepé (Ice Hill), breached on the south, and sending a stream of lava around itself to the north. Some other second-period cones are shown in the map, but the only remaining one of present interest is Aï Tepesi (Moon Hill), situated on the schistose ridge running north and south, northwest of Kula and south of Güldé. This volcano has sent a stream of lava about three kilometres to the southeast,

* Shown in Plate II, 1, to the right of Kula Devlit.

its end being near a spring of cold, clear water, on the road to Menné.

Third-Period Cones.—But the chief feature of the landscape and main point of interest of the Kula Basin is the volcano (cf. Pl. II, Fig. 1) called Kula Devlit * by the Turks and Kaïmeni Devlit by the Greeks.† This cone has a height of 165 metres above the plain below, or 885 ‡ above sea-level. Its sides slope at an angle of 30° 30.′ The ascent, owing to the lapilli and scoriæ with which it is covered, is very fatiguing, but the summit once gained we get a splendid and striking view over the whole of the Kula Basin. To the north our range is bounded by the Demirji Dag, with glimpses of the Gediz Chaï flowing from the northeast, to the east the hills that shut out the view of Ushak, on the south the Konurja Dag, which we crossed coming from Ala Shehir, and to the west a low ridge studded with second-period cones, and with Kara Devlit showing beyond it. At our feet lies a field of black lava stretching to the Gediz on the north, with the second-period cones already described, and beyond its borders the green cultivated fields of the alluvial deposits, forming a striking and wonderful contrast to the barren blackness of the lava, and which I can only compare for sharpness of contrast with the view of the Nile Valley from the cliff at Assiut, or the top of the Great Pyramid. Immediately to the south lies the picturesque town of Kula, its white houses and numerous minarets forming a very pretty picture against the black and green background. To the northwest we get a glimpse of the village of Gülde, and to the east lies Köros Köi. For picturesqueness indeed some of the views about the Kula Basin surpass those that I have seen in similar regions, the oriental features adding a character which is lacking elsewhere. The cone itself is almost bare of vegetation, except for a few wild oats, a little grass, and some small blue flowers on the southern rim of the crater, which is about ten metres wide, and on whose highest point is a small Greek chapel.

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* Hamilton (*op. cit.*) calls this Kara Devlit. At the present day this is the name of the cone near Menné.

† The word "devlit" means properly "state, government" (Redhouse, Turk. Dict., *s. v.* p. 571). At Kula it seems to have the signification of "mountain." The authors quoted all translate it "inkstand," but for this I could find no authority. Cf. v. Diest (Von Pergamon . . . zum Pontus, Peterm. Mitth. Erg.-Heft 94, p. 40), who likewise translates "inkstand."

‡ Hamilton makes it 867. Both determinations are barometric.

The crater of Kula Devlit is some three hundred metres across, oval in shape and double, a smaller and later crater occupying the southwest corner of the larger, the ejections from which have helped to raise the southern rim to its present greater height. The larger crater wall is quite perfect except at the east side, where it has been broken down by a comparatively early stream, the surface of which is almost invisible owing to the accumulation of lapilli and sand over it. The inner walls of the two craters, which slope at an angle of 30°, are composed of loose lapilli, with here and there large masses of scoria and vesicular lava, in some of which were found inclosures of rock brought up from below. The lapilli and scoriæ show few signs of decomposition, due doubtless to the fact that the rain-water soaks rapidly through them owing to their porous character. Probably owing to the same cause there are no gullies affording natural sections where the structure of the crater walls can be studied. There seems not much reason, however, for doubting that the cone is entirely a cinder cone, with no lava-flows in it except, perhaps, near the base.

The lava streams of Kula Devlit have all, as far as can be seen, broken out beyond the flanks of the cone, with two exceptions, one the older stream mentioned above, and the other a short ridge of lava on the south flank, near Piresik Devlit. The main streams form two large lava fields, one to the south and southwest, and the other to the north and northeast, as shown on the map.

The former field is seen to belong to at least two distinct periods of activity. To the first belong what may be called "knolls"; rough and jagged bosses and hummocks of rock, of which over thirty were counted to the southeast of Kula Devlit. These vary form 3 to 20 m. high, above the later stream, and 15 to 60 m. broad at their base. The later lava stream flows round them, leaving generally some space between. These "knolls" seem not to be cones or domes, marking special local eruptions, but are apparently merely masses of lava which have been heaped up in the course of flow of the stream beneath. What cause produced such peculiar localization of the crust and lava I cannot well say. In some cases they seemed solid hills of lava, a few scoriaceous above, and more compact below, but split by clefts and crevices, some of which are 20 m. deep, and at the bottom of which are seen the bones of sheep, etc., brought there by wolves and jackals. In the crevices and hollows of these "knolls" grow some tufts of grass and flowers, and occasionally a shrub or a wild fig-tree. Cf. Pl. II, Fig. 2.

The latest flow forms a nearly level * plain of black lava, whose surface is extremely rough and jagged—the "cindery" surface characteristic of viscous streams † (one exception to this is noticed later). A coating of dark-green moss has grown over this, making the jagged edges still more slippery, and walking still more difficult. Apart from this moss no vegetation whatever is seen on this field. To the southeast the latest flow ends east of the northeast corner of the town of Kula, but some "knolls" are to be seen projecting above the alluvial deposit for some distance farther south. In places also two streams can apparently be distinguished, one above the other, the lower much more compact and with, in some instances, a columnar structure. This columnar struture is also to be seen in the lower part of the upper streams, in a few places. The columns are 5–25 cm. thick and 25–40 cm. long, irregular in shape, and radiating perpendicularly to the uneven surface.

The southwest stream of Kula Devlit, which, while petrographically apparently distinct, yet shows no marked line of demarcation, runs to within a few metres of the foot-hills of the mountain ridge, leaving barely room enough for the road to Güldé and Kavakly. The stream shows fewer "knolls," and, if anything, is less scoriaceous than the southeast stream, but is not as deep—the latter having flowed into the channel of a small stream to the east of the site of Kula, choking it up and giving rise to a small lake.

The largest stream of all is the north stream, which, starting from the east side of Kula Devlit, flows to the Gediz Chaï, a distance of about 10 km. It is at first confined on the south by two small second-period cones, and farther on it seems to have followed a stream bed to the Gediz, which river it turned out of its course to some extent, and now at its northern extremity forms a perpendicular cliff of lava 10–20 m. high. The upper part is vesicular for about two metres, the next six or seven are columnar, and the lower part very compact and hard.‡ There seem to be some "knolls" also in this lava field, but I went very little over its surface. This stream seems to belong, on petrographical grounds, to the same

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* The lava field at the base of Kula Devlit is 30 m. above the level at the town, giving a slope of about 1.5 per cent.

† Cf. Geikie Text-book of Geology, 1893, 217.

‡ Cf. Ham. and Strick., *op. cit.*

period as the later southeast stream, and at the Gediz Bridge (so-called Bogaz Köprüsü) there underlies it a second-period stream.

The only large third-period cone besides Kula Devlit is one about 1.6 km. W.N.W. of the latter, called Kara Tepé (Black Hill). This is a scoria cone, 60 m. high, breached on the west side, and showing a stream of lava which, after flowing a short distance west, turns north, then northeast, and runs round a nameless breached cone near Böz Tepé. This crater and lava stream represent by far the youngest eruption of all, judging from its state of preservation. The scoria is, as the name of the cone denotes, mostly black and in a wonderfully fresh and undecomposed condition, the thinnest threads and partition-walls being still fresh and whole. To the east of Kara Tepé is a small westward-flowing stream, with the "ropy" surface characteristic of rather fluid streams. As some of the "knolls" show the same character and are similar to the lava of this stream petrographically, this short stream may be assigned to the "knoll" outflow of Kula Devlit.

To the north of Kula Devlit rise numerous small cones and domes, 20–30 m. high, generally oblong, and many with their long axes pointed toward Kula Devlit. These are covered with scoriæ and lapilli, and, as they are small and show no crater depression, are held to be domes (Kuppen). They arise in a field of older lava, smooth and covered with sand and lapilli, but belong themselves to the third period, and perhaps to the latter part of it.

Alluvium, etc.—The town of Kula lies at the north edge of a small, fertile triangular plain, 690 m. above sea level. As shown by a well-digging, spoken of later, the town is built chiefly on an old second period stream, perhaps from Piresik Devlit, the northern part of the town being on the edge of, and partly built on, the southern Kula Devlit streams. On the east flows the small stream of Kula Su, which starting as a brook in the Konurja Mountain, runs northerly and empties into a marshy lake formed by the damming of the brook by the southeast lava stream.

The alluvial deposit on this small plain is fertile but not very deep. A similar plain lies between the north lava stream and the easterly range of schist.

In the lava bed itself no springs are found, though at two or three places one finds large jars kept filled with fresh water for the benefit of the thirsty traveller—a charitable custom of the Turks. At the foot of the schistose mountains springs are quite common, furnishing clear, cold water. At Hammamlar (the Baths), about 12 kilometres north-northeast of Kula, are two hot sulphurous springs, of which the hotter has a temperature of 58° C.* The ruins show this to have been the site of an ancient town, though I found no traces of the theatre Hamilton speaks of. About two kilometres nearer Kula, on the right-hand bank of the Gediz Chaï, a spring strongly charged with CO_2 and having a very faint taste bubbles up. Hot springs and baths also exist at Ala Shehir.

Petrographical Description of Eruptive Rocks.

The rocks collected and examined consist of specimens from outflows of the second and third periods, mica schist and hornblende schist from the Konurja Mountains to the south of Kula, and one or two others to be described later. Of these, those from the lava streams are the most important and interesting, and to them we shall chiefly devote our attention.

Eruptive Rocks.—The eruptive rocks of the Kula Basin present many interesting features, some of which are common to all of them, thus forming a very good example of what Vogelsang† first called "Geognostische Bezirke," and what Judd‡ later called "Petrographical Provinces." Iddings,§ in a recent paper, speaks of this relation as "Consanguinity of Rocks," but without referring to Vogelsang. A "petrographical province" is a district of any extent where all the allied rocks possess certain features in common, of structure or chemical or mineralogical composition, etc., which perhaps may not be readily defined, but which are characteristic of the region, distinguishing the rocks of this district from similar rocks of other districts. One can compare these "provinces" to the various "schools" of painting or sculpture, and once the characteristic features of the group have been grasped, one can state with much certainty whether a given rock comes from that district or not. The three authors quoted all give examples of this

* Hamilton, Researches, etc. II. p. 140.

† Vogelsang, "Ueber die Systematik der Gesteinslehre, etc." Zeit. d. deutsch. geol. Gesell. 1872, p. 507.

‡ Judd, "On Tertiary Gabbros, etc., in Scotland and Ireland." Q. J. Geol. Soc. 1886, p. 54.

§ J. P. Iddings, "On the Origin of Igneous Rocks." Bull. Phil. Soc. Washington, 1892, p. 128 ff.

"consanguinity," of which Vogelsang's are the best and most numerous, and the rocks under present consideration form another.

This will be spoken of again, but the whole subject is an important one, deserving of more study and attention than has hitherto been given to it.

The Kula eruptive rocks are composed of plagioclase, augite, hornblende, olivine, magnetite, and glass, some with leucite and apatite, and a few secondary minerals; and are to be classed as basalts, more exactly hornblende basalts. Further, they are to be subdivided into hornblende-basalts proper and hornblende-leucite-basanite. It was at first rather doubtful as to whether they were to be called andesites or basalts, their generally andesitic structure and the relatively small amount of olivine inclining one to the former name. But finally their basic composition, as determined by chemical analysis, the character of the feldspar, the constancy of the presence of olivine, the presence of leucite in some of the streams, and the peculiar alteration of the hornblende, hitherto observed only in basalts,* show that they really belong to the latter group.†

These basalts are all porphyritic, and may be further subdivided according to the structure of the groundmass into—

(*a*) Those with a hypautomorphic, granular structure, containing glass, which we may call "normal" basalts.

(*b*) Those with a true hyalopilitic structure.

(*c*) Very glassy forms, or semi-vitreous basalts.

(*d*) Tachylytes, almost pure glass.

To the first belong all the second-period lavas examined, while the third-period flows belong entirely to the last three groups. It must be remarked, however, that these groups shade into one another, and no very sharp line can be drawn between them.

But before taking up the rocks themselves the component minerals may be described.

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* Küch (Petrographie d, Rep. Colombia in Reiss u. Stübel, Reisen in Südamerika, Berlin, 1892), having examined 600 slides, and Belowsky (Petrog. Rep. Ecuador in ditto), with 250 slides, chiefly of hornblende-bearing andesites, did not once observe this alteration.

† C. Vogelsang (Trachyte u. Basalte d. Eifel, Z. d. d. geol. Gesell. XLII. 1, 1890), in describing the hornblende-basalt of Brinkenköpfçhen, remarks that, owing to the great deficiency in olivine and some of its microscopic characters, it has an andesitic character. Cf. Zirkel, Basaltgesteine, 117.

Component Minerals.

Feldspar.—The feldspar of these basalts seems to be constantly a plagioclase, but its quantity is relatively so small and the crystals so minute that it was impossible to effect a separation of any of it for separate analysis. The result of an optical examination shows, however, that it belongs towards the anorthite end of the series. It occurs in two distinct forms; either xenomorphic, or in well-formed automorphic* crystals. The first is seen only in the first sub-group mentioned above, the normal basalts, where it forms part of the groundmass, in leptomorphic grains, together with colorless glass. In this form few of the sections show twinning lamellæ, and it is possible that some of this feldspar may be orthoclase, though the small percentage of K_2O present makes it very doubtful.

The second mode of occurrence is much more frequent, the feldspar here being in small laths and long crystals. These are present in the groundmass of all the basalts, even in those of the first group, though in one or two of the tachylytes and semi-vitreous basalts they are so sparingly present as to be almost unnoticed. In these last cases it seems that the whole mass solidified before the feldspar, which is one of the last of the minerals to separate out, had crystallized. These small crystals are colorless and clear, and twinning lamellæ are very common. Some twinned lamellæ giving almost symmetrical extinction were measured, the best giving angles of 31° 10′ and 29° 45′, which corresponds to a bytownite. In size they vary from 0.01–0.10 mm. in length, and often show a fluidal arrangement, together with the augite microlites, with which, on account of their small size, they are readily confounded.

Augite.—The augite is present in a relatively very small quantity for a basalt.

Megascopically it is seen occasionally as crystals from 1 to 3 mm. long, of a clear greenish-yellow color, only to be distinguished by the eye from olivine by the perfect cleavage.

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* The terms *automorphic* and *xenomorphic* are used throughout this paper instead of Rosenbusch's terms *idiomorphic* and *allotriomorphic*, both on the ground of priority, they having been used by Rohrbach in 1886 (Min. pet. Mitth. VII. 1886, p. 88), and because they are shorter and etymologically more correct.

Microscopically the largest augites are colorless, or nearly so, of a very pale fawn-gray color, and are generally fragments, presenting both well-developed crystallographic planes and broken edges. The cleavage is not well developed.

Those of a smaller size are well-formed crystals, from 0.1–0.4 mm. long, generally elongated parallel to the *ć* axis, but quite stout in proportion to their length. The planes observed were *a*(100), *b*(010), *m*(110), *u*(111), *s*($\bar{1}$11), *p*($\bar{1}$01).* They are either colorless or of the very pale brown color mentioned above, and show no pleochroism. Occasionally crystals were seen with an irregular inner core of a pale greenish gray, which is pleochroic as follows : $\mathfrak{c}$ = dark greenish gray, $\mathfrak{b}$ and $\mathfrak{a}$ light greenish gray, $\mathfrak{c} > \mathfrak{b} > \mathfrak{a}$. The extinction angle of this greenish core is about the same as that of the colorless border, in some cases a few degrees more. The angle of extinction of the colorless augite varies from 26° to 43°, most of the measurements lying between 37° and 39°.

The augite is always clear and does not show the prismatic cleavage very distinctly, as a rule. Inolusions are not very common, and are generally either clear, mostly brown, glass, or groundmass. Some crystals were seen with a core of groundmass, of the shape of the surrounding crystal. Hornblende is occasionally included, and magnetite is very rare. It was noticed that in some crystals in which the plane *s*($\bar{1}$11) was present, small opaque black grains were included, forming a narrow line parallel, and close, to this plane alone, none of them being present in the rest of the crystal.

Twins are not common, and are almost all to be referred to the usual twinning plane, *a*(100). Some "augite stars" and groups of crystals, apparently twinned about the planes *y*(101) and *W*($\bar{1}$22), were seen, and one large augite crystal had two thin twinning lamellæ at an angle of 27° with the cleavage cracks, the twinning plane being perhaps *W*($\bar{1}$22).†

In many of the more glassy varieties, especially in some of the semi-vitreous basalts, the augite showed the well-known "hour-glass" structure,‡ in some cases with interesting modifications, two

* The crystallographic positions, symbols, and lettering adopted throughout this paper are those given in Dana's Mineralogy, 6th Ed. 1892.

† Cf. Rosenbusch, II. 662.

‡ This was first observed by v. Werveke (Beitrag zur Kenntniss der Limburgite. Neues Jahrb. 1879, p. 483). Descriptions are also given later by Ver-

of which are here shown. In the one (Plate III, Fig. 3) the section parallel to *b*(010) shows under crossed nicols a division into five parts, i.e., four border trapezoids and a central rhomboid. These do not extinguish alike, the end divisions extinguishing in one direction at an angle of 42° 10′, while the central and side divisions extinguish at just about the same angle, but in an opposite direction. The central and side parts do not, however, extinguish precisely together, there being a barely perceptible difference, and the effect of the whole is to give the augite section the appearance of a low, truncated, rhombic pyramid. A rather more complicated, but analogous, form is shown in Fig. 4. Dannenberg observed the same structure in nepheline basalt from the Leilenkopf, near the Laacher See, and gives a figure, but his observed extinction angles differ materially from mine. In fact none of the recorded observations agree in this respect among each other, as is to be expected from the mode of formation of the structure. Besides these regular structures, augite crystals were seen built up of many, most irregularly-shaped, segments, which have straight edges and are sharply defined under crossed nicols, but most unsymmetrically arranged.

A regular zonal structure is also frequent, the outer zones having, as a rule, a larger extinction angle than the inner. The zones are often sharply distinguished from each other, in other cases not so, the darkness sweeping without a break, like a wave, from the centre to the circumference.

The last-formed augite consists of very small microlitic crystals, their length being from four to ten times their thickness. They are clear and generally colorless, but occasionally show a faint greenish tinge. It was at times hard to distinguish them from plagioclase laths, and some of the microlites which are grouped under the head of augite are almost certainly to be referred to apatite, judging from the amount of P_2O_5 found in the basalt. These microlites are thickly scattered through the basis of colorless or brown glass, and give to many of the rocks their hyalopilitic structure.

Hornblende.—Of all the minerals composing the basalts of this

beck and Fennema (Neue geol. Entdeckungen auf Java. N. J. II., Beil.-Bd., 1883, p. 212), Petzold (Basaltgesteine der Rhön. Inaug. Diss. Halle, 1883. p. 20), C. A. Müller (Die Diabase aus dem liegenden des Ostthüringischen Unterdevons. Inaug. Diss. Gera, 1884, p. 21), Dannenberg (Der Leilenkopf, etc. Jahrb. d. k. preuss. geol. Landanstalt, 1891, p. 110).

reigon the hornblende offers the most interesting features and is the most characteristic and most constant in its presence. Its constancy, in fact, is perfect, it being present as the prominent constituent in all the Kula basalts; those of the earliest and those of the latest streams, those with and those without leucite, those with much olivine and those with little, in the purely glassy tachylytes as well as in the basalts of a normal structure. It is, in fact, the stamp and seal of the Kula basalts.

Megascopically it is much more frequent and prominent than either the augite or the olivine, and occurs as black phenocrysts, from 2 to 4 mm. long, some few reaching a length of 6 to 8 mm. The larger crystals have their surfaces pitted and corroded, and the crystallographic planes present do not admit of even approximately exact measurement. The smaller crystals and needles are very bright and fresh-looking.

Microscopically it is seen that the hornblende invariably occurs as porphyritical crystals, never as a constituent of the groundmass. It is, as a rule, well crystallized, showing combinations of the planes, $c(001)$, $a(100)$, $m(110)$, and $r(011)$, occasionally elongated parallel to $\dot{c}$, but usually in stout, thick crystals. The long prisms reach a length of 5–8 mm., and the short, stout crystals a length of 3–4 mm., but they commonly vary from 1–2 mm., and from this run gradually down to 0.2 mm. Twins are not common and have the usual twinning plane, $a(100)$. Some intergrown crystals may represent other twinning laws, which, however, could not be determined.

The cleavage is very well marked, though in some of the more glassy rocks the cracks seem to be less easily developed in making the slide than in the less glassy.

The color is generally yellowish brown, as is the case with basaltic hornblende, but some greenish-yellow individuals were seen, often both present in the same slide. This green variety shows a marked fondness for the more glassy rocks. Both varieties are strongly pleochroic, the brown as follows : $\mathfrak{c}$ = dark yellowish brown, $\mathfrak{b}$ = yellowish brown, $\mathfrak{a}$ = very pale fawn-gray, with $\mathfrak{c} > \mathfrak{b} > \mathfrak{a}$. The green variety shows the following pleochroism: $\mathfrak{c}$ = dark brownish green, $\mathfrak{b}$ light greenish brown, $\mathfrak{a}$ pale fawn-gray, the absorption being the same as before. The extinction angle varies from 4° to 14° 30′, in one case being as high as 23°.

The hornblende crystals very commonly show a zonal arrangement of color. This is more frequent in the large crystals, the small ones being generally of one (light) color. It is also more common in the more glassy rocks, though perhaps an explanation of this is that in the less glassy the hornblende has undergone profound alteration, thus obscuring the original structure. These zonally built crystals show a dark core, and, surrounding this, a light border, both being of the same color, but of different depths of tint, as the zonal arrangement is seen in both the brown and the green varieties. Occasionally the dark core is lighter towards the centre, and very rarely the darker zone is the outer one. Only in a few cases were four or five alternately dark and light zones observed. While instances occur where the extinction angle is the same in both zones, yet there is, as a rule, a small difference, generally from 3°–5°, in one case as much as 9° 40′, the extinction angle of the dark zone being the greater.

This zonal structure of hornblende has been frequently observed,* and appears to be analogous to the zonal development of the triclinic feldspars, i.e., due to superposed growths of different minerals of the same group. Oebbeke expresses the opinion "that the border is not monoclinic, but triclinic." (According to the figure he gives, it would seem that the inner dark *core* is meant.) As far as my observations go, this seems not to be the case, at least in the Kula basalts, as in sections parallel to $a(100)$ both zones extinguish parallel to the single system of cleavage lines, and in horizontal sections the direction of extinction in both exactly bisect the angles of the cleavage rhombus. One exception must, however, be noted, where the lighter centre and outer border extinguished parallel to the cleavage cracks, in a section parallel to $a(100)$, while the dark zone between has an extinction angle of 10° 30′.

An interesting feature is that the dark inner core frequently shows a corroded outline, and then the outer edge of the surrounding light zone follows this line very exactly, the small curves and irregularities of the inner line being often faithfully reproduced in the outer, the result being a band of equal width around the dark core. This proves that the dark hornblende was first formed and

* Cf. Rosenbusch, *op. cit.* 3te Auf. I. 558; Hyland, Gesteine des Kilimandjaro, Min. pet. Mitth. x. 243; Oebbeke, Beiträge z. Petrographie d. Philippinen, etc., N. Jahrb. Beil.-Bd. I. 1881, p. 451; Rudolph, Petrographie d. Anden v. Peru u. Bolivia, Min. pet. Mitth. IX. 296.

suffered corrosion, and at a later stage a hornblende containing less iron was crystallized about this.

Inclusions are not very common, being chiefly glass, either colorless or clear brown, or, more frequently, containing microlites, like the glassy groundmass. These glass inclusions are frequently arranged in a definite way, either parallel to the crystallographic boundaries of the crystal, or in a similarly-shaped cluster or kernel in the centre. One long crystal has a line of small brown glass inclusions down the central line. Here and there four or six-sided sections are seen, which show a large similarly-shaped glass core, occupying nearly the whole of the crystal space, and leaving only a thin shell of hornblende around it. Augite is also a not infrequent inclusion in hornblende, this being much more often the case than the converse. Magnetite is rarely seen as an inclusion in hornblende, though as an alteration product it is very common, as will be seen later. In one or two large hornblende crystals inclusions of long colorless needles were seen, but their optical properties could not be determined, and no cross-sections were found. They are probably apatite, being much longer and larger than the microlites of the groundmass.

There is no doubt that in the Kula basalts the hornblende is an essential, original constituent, though in the case of some other basalts this does not seem to be quite so certain. Here, however, its constant presence—much more constant than that of either the olivine or the plagioclase—its well crystallized form and uniform method of alteration, and the inclusions of augite and groundmass, are all against any other interpretation of its presence.

Alteration of Hornblende.—The changes undergone by the hornblende subsequent to its crystallization fall under the three heads of mechanical deformation, simple corrosion and magmatic alteration. The first two may be passed over with a few words, but the consideration of the latter will occupy more of our space. It may be mentioned that decomposition due to atmospheric influences was not noticed in the hornblende, and is not here spoken of.

Several distorted crystals were seen, and the larger crystals are frequently broken, though this latter is not as common as is the case with the augite and olivine.

Simple corrosion, or disappearance of part of the crystal through magmatic resorption, is quite common, deep bays and pockets being often formed, which are now filled with groundmass. In all these cases of simple resorption a production of new-formed substance has not taken place. This form of corrosion, again, is not as common in the case of the hornblende as with the olivine or augite.

Another change which may be ascribed to corrosion is what has been called a "melted appearance" of the crystal, when the sharp edges are rounded and the crystal reduced to an ellipsoidal or approximately spherical shape. This "melted appearance" is always accompanied by profound alteration of the crystal, and will be spoken of later in connection with the latter. The corrosion of the inner dark core has been already referred to.

We now come to what is perhaps the most interesting and characteristic feature, not only of the hornblende, but of the basalts as a whole—the magmatic alteration and alteration products of the hornblende. These are of three kinds:

a. The change of the light-colored hornblende into a dark reddish-brown, almost, opaque variety, without any evident change of form.

b. The formation of a border or mass of augite and opacitic grains.

c. The formation of a reddish-brown mineral, occurring in long so-called "club-shaped" (keulenförmig) crystals, accompanied by augite and opacite grains.

The first form of alteration may be dismissed with a few words. It is seen almost exclusively in the scoriaceous specimens, and the darkening takes place on the outer parts of the crystal or along cracks. There is no change of form or separation (ausscheidung) of other minerals, and the result seems to be identical with that observed by other writers, and that produced by the action of molten magmas on hornblende in some experiments.*

The second mode of alteration is very frequent in all eruptive rocks,† and has been described by many writers,‡ so that it will

* Oebbeke, *loc. cit.* p. 474; Lagorio, Die Andesite des Kaukasus (Dorpat, 1878), p. 25; Becker, Ueber d. dunklen Umrandung der Hornblenden, etc., N. Jahrb. 1883, II. 3; Belowsky, *loc cit.* p. 37.

† It is rare among the plutonic rocks, but common in the volcanic rocks, especially in the more basic of them, being frequent in the basalts and andesites, and almost unknown in the rhyolites.

‡ Hyland, Gesteine d. Kilimandjaro (T. M. P. M., 1888, x. 240), gives an almost complete list of the literature of this and the following form of alteration. To this may be added the following:

not be described in detail here. (Cf. Pl. IV, Fig. 2.) Suffice it to say that the hornblende becomes changed into a mass of colorless augite and black opaque grains, in many cases accompanied by a rounding of the sharp edges, but in the Kula basalts generally with the preservation of its original form. The black grains, called provisionally opacite, are commonly held to be magnetite, a view with which Becker does not agree. I am inclined to think them—at least the greater part—magnetite, on account of their exactly corresponding appearance with the undoubted magnetite of the groundmass The question is a hard one to settle definitely, owing to the great difficulty of separating these minute particles from the containing minerals.

That most of the colorless grains are augite * there is no doubt, as they offer the same optical characters as the larger augite crystals in the groundmass, and augite crystals included in the hornblende, showing the same peculiar blue and yellowish polarization colors, and being often—but not always—orientated like the hornblende.

There are also seen between the augite and opacite grains some particles of a colorless mineral the nature of which is undetermined. Lenk, in the case of some Rhone basalts, compares it to nepheline, but shows that it cannot be that mineral. A similar occurrence in andesitic hornblende from Chapultepec he calls feldspar, as does C. Vogelsang in hornblende-andesite from the

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Rosenbusch, Mikr. Phys. II. *passim.*

Streng, Ueber d. Hornblendediabas v. Gräveneck. XXII. Ber. d. Oberh. Ges. f. Nat. u. Heilk. p. 241.

Renard, Notice s. l. Roches d. l'isle de Kantavu. Bull. Acad. Roy. d. Belg. (3) XI. No. 3.

Lenk, Geol. Kenntn. d. südl. Rhön. Verhandl. d. phys.-medic. Gesell. z. Würzburg, N. F. XXI, 1887.

Lenk, Geol.-petrog. Mittheil. ü. d. Valle de Mexico. Habilit Schrift (Leipzig, 1890), p. 17.

Renard, Petrology of Ocean. Islands (London, 1889), 129.

C. Vogelsang, Trachyte u. Basalte d. Eifel. Zeit. d. d. geol. Gesell. XLII. 1, 1890, p. 13.

Osann, Beitr. z. Kenntn. d. erupt. Gest. d. Cabo d. Gata. II. Zeit. d. d. geol. Gesell. XLIII, 1891, p. 688.

Osann, Basalt fr. Southern Texas. J. of Geol. I. 344.

Küch, *loc. cit.* p. 55; Belowsky, *loc. cit.* p. 44; Herz (*ditto*), p. 116.

* Kotô (Studies of some Japanese Rocks, Q. J. Geol. Soc. 1884, p. 439) was the first to show that these grains were really augite.

Kelberg, in the Eifel. Doss * also observed it, but expressed no opinion as to its nature. It seems to me probable that it is feldspar, but I can give no definite proof one way or the other.

The third effect of alteration may be regarded in most cases as a first stage of a process of which the formation of an augite-opacite aggregate is the second and final one. The characteristic feature of this alteration, which has been previously observed several times, is the presence of a reddish-brown mineral, occurring in long crystals, sometimes thicker towards one end, whence the name "keulenförmig" (club-shaped) applied to them. (Cf. Pl. IV, Fig. 1). Their terminations, while pointed, do not seem to be strictly crystallographic, and the cross-sections observed were irregular in outline, and as far as could be seen not bounded by crystallographic planes. In length they vary from 0.16–0.05 mm. by 0.03–0.005 mm. thick. Some appear to show cleavage parallel to the long axis.

In color they are reddish brown to greenish brown, and are strongly pleochroic; parallel to the long axis olive-green, and at right angles to this light brown and dark red-brown respectively, the last showing the greatest absorption, and the first the least. They are thus shown to be biaxial, as is also indicated by the fact that no isotropic sections were seen. The extinction appeared, in every case, to be parallel to the long axis. In many cases the brown individuals are so light in color, and so sharply developed and separate from each other, that I had excellent opportunities for observation. This is remarked, inasmuch as, in regard to the extinction, my results differ from those of most other observers, as will be seen later.

These crystals lie, not in an irregular and confused way, but the majority of them arranged parallel to the $\dot{c}$ axis of the hornblende crystal, while others cross these at angles of about 60° in either way, the measurements varying from 57° to 67°. These obliquely-lying crystals are generally found along the sides of the hornblende crystal, those in the interior being mostly parallel to the $\dot{c}$ axis. In horizontal sections of hornblende crystals most of the small crystals lie in planes parallel to the pinacoids and prisms of the hornblende. Occasionally at the ends of large hornblende crystals, seen in section parallel to $\dot{c}$, the brown crystals are

* Doss, Die basaltischen Laven, etc., der Hauran, etc. Min. pet. Mitth. VII, 1886, 514.

grouped in tufts, shaped like a half-opened fan, and spreading towards the interior of the hornblende. The brown crystals at the sides of the hornblende individual lie at angles of about 60° wsth the vertical edge.

Filling the interstices between the brown crystals are magnetite and colorless augite grains, with a few grains of the undetermined mineral spoken of above. The brown aggregate (which for the sake of convenience we shall call this mixture of brown mineral, augite and magnetite) is formed along the outer surfaces of the original hornblende, and also on the sides of cracks, and on some broken or corroded surfaces. In a few cases large fragments of hornblende crystals show this alteration on the original planes, while the fracture edge runs across both the fresh and the altered substance. It seems to show a preference for the brown variety of hornblende, and especially for the dark form of this. In many cases the inner dark core is altered to brown aggregate, while the outer light zone is unchanged, showing that the dark hornblende was first altered and the lighter colored hornblende subsequently deposited on the surface.

It is to be remarked that this alteration to brown aggregate has taken place in nearly every case without marked change of the original form or surfaces of the hornblende crystal, though in some cases the altered hornblende has undergone corrosion, like the unaltered, but not to as great an extent.

It has been already stated that the two last-described alterations are apparently separate stages of one process, and the following facts may be adduced in favor of this view. The hornblende crystals which have been altered to brown aggregate near the outer surface or along cracks have the rest of their substance perfectly unaltered. (Pl. IV, Fig. 1.) Sometimes the alteration has proceeded so far that only a small kernel of the original hornblende is left, and again none remains, the whole of the hornblende being altered. Very often an augite-opacite border is seen around the brown aggregate, though it also happens, but more rarely, that the augite-opacite border is present without the brown aggregate. In the former case the hornblende crystal is made up of a kernel of unaltered hornblende, around this a zone of brown aggregate, and again outside this a ring of augite-opacite aggregate, with generally the line of demarcation between the last two very ill-defined. This may be called the second stage, the third being where all the hornblende substance has disappeared, giving place to a core of brown aggregate and an outer zone of augite-opacite. The last stage is where the brown aggregate has entirely disappeared and there remains of the hornblende nothing but a so-called "pseudo-crystal" of augite-opacite aggregate, with or without change of form. (Pl. IV, Fig. 2.)

These last two stages are beautifully shown in the second-period basalts, especially in that from a well-digging in the town of Kula, to be spoken of later. It must, however, be remarked that an alteration to brown aggregate seems to be not necessary to the formation of the augite-opacite aggregate, but that the hornblende itself is readily changed into the latter without the preliminary formation of brown aggregate. This observation agrees with those of other observers, and an explanation of it is given on a following page.

The most striking fact in connection with these two alterations is the perfect manner in which the original hornblende crystal has as a rule preserved its form, notwithstanding the great chemical changes it has undergone. Taking into consideration the fact that the new product is granular and not compact, the outlines are wonderfully sharp, allowing of quite exact measurements of the angles presented by the sections. Doelter and Hussak * mention the same fact in regard to hornblende which was subjected to the action of a molten basaltic magma in two of their experiments, and several instances of the same phenomenon in nature will be found in the literature on the subject.

There are, however, exceptions, chiefly in the last stage, and in the second-period basalt. Here, as already mentioned, the altered hornblende crystals are rounded and present an appearance which, Sommerlad † graphically says, looks as if they had melted and run, or, as Hyland puts it, looks as if they had been "washed." These rounded forms chiefly occur in the case of the smaller crystals, and almost always when they have been completely altered to an augite-opacite aggregate. Some cases were seen where the brown aggregate has evidently been disintegrated and scattered through the substance of the rock. In two cases a large augite (one with

* Doelter and Hussak, Ueber die Einwirkung geschmolzener Magmen auf verschiedene Mineralien. N. Jahrb. 1884, I. p. 24.

† Sommerlad, Ueber hornblendeführende Basaltgesteine. N. Jahrb. II. Beil.-Bd. 1883, 141.

an accompanying olivine crystal) had surrounding part of it (and of the olivine) a "mantle" or fluidally arranged covering of brown aggregate, and in other cases particles of brown aggregate are scattered as inclusions through large clear augite crystals. In one or two instances inclusions of well-shaped hornblende crystals altered to brown aggregate were seen in augite crystals. All these cases are exceptional, but taken together seem to show that the augite was formed at about the same time that the alteration of the hornblende was taking place, in the first cases the augite having evidently been formed before or at the same time, and in the others subsequently. It must be also noted that no instance was seen of an augite inclosing hornblende altered to augite-opacite.

The Kula basalts are all very glassy, yet it was observed to be the rule that the more glassy the rock the less the alteration, the last stages being reached only in the least glassy varieties. This fact has also been observed by many writers, including Rosenbusch, Hyland, Lenk, Petzold, and Küch.

To return to the brown aggregate stage of alteration, there is given in a note * the literature on the subject so far as the writer's knowledge of it extends. From an examination of this it will seen that, first observed by Zirkel in 1870 in the basalt of the Nürburg in the Eifel, it has subsequently been found in basalts of

* Zirkel, Basaltgesteine, p. 26.

Rosenbusch, Mik. Phys. 3te Aufl. I. 560.

Möhl, Die Basalte u. Phonolithe Sachsens (1873), p. 130.

Van Werveke, Beitr. z. Kenntn. d. Gesteine d. Insel Palma. Neues Jahrb. 1879, p. 825.

Bücking, Jahrb. d. geol. Landesanstalt, 1880, p. 160.

Sommerlad, Ueber hornblendeführende Basalte. Neues Jahrb. 1882, II. Beil.-Bd. p. 150.

Petzold, Basaltgesteine der Rhön. Inaug. Diss. Halle, 1883. p. 26.

Doss, Die basaltische Laven und Tuffe der Haurân. Min. pet. Mitth. VII, 1886, p. 515.

Lenk, Zur geol. Kenntn. der südl.-Rhön (Würzburg, 1887), p. 79.

Hyland, Ueber die Gesteine des Kilimandjaro. Min. petr. Mitth. x, 1888, p. 238.

Hatch, On the Characters of Rocks collected in Madagascar. Q. J. Geol. Soc. 1889, p. 349.

C. Vogelsang, Trachyte und Basalte der Eifel. Zeit. d. deutsch geol. Gesell. XLII, 1890, p. 19.

Osann, Beitr. z. Kenntn. der. Gesteine des Cabo da Gata. II. *Ditto*, XLIII, 1891, p. 688.

Zirkel, Lehrbuch d. Petrographie, 1893, I, 719.

Saxony, Palma, the Rhone, the Haurân in Syria, Kilimandjaro, Madagascar, and Cabo de Gata. All these hornblende basalts seem to have been poor in glass, and most of them to have contained nepheline, as is usually the case in hornblende basalts, though in the present instance none was found. The descriptions of the brown mineral agree perfectly, except in one point, with my own observations. Through the kindness of Prof. Dr. Zirkel and Dr. Lenk, I was also able to examine slides of the basalts from the Eifel, and the Spahler Berg and Sparbrod on the Rhön, and establish the identity of these occurrences with my own. The exception spoken of is the oblique extinction which almost all the writers observed, varying from "parallel or little inclined" (van Werveke) to maxima of 20° (Hyland) and 25° (Doss), the usual extinction angle lying between 7° and 15°. It is to be noted that Doss (p. 515) observed in one or two specimens from the Tell Sfech that the altered hornblende contained not only small, dark-brown, club-shaped "hornblende" crystals, but also small "rod-like," yellowish-red to yellow crystals which have parallel extinction and whose chemical nature is undetermined. Similar contradictory statements are made in regard to the behavior of the brown crystals towards hydrochloric acid, some of the authors stating that they are, others that they are not, acted on by it.

The general opinion is that these "club-shaped" bodies are also hornblende, though Petzold, Hyland, and Lenk are inclined to doubt this, and leave the question an open one. The smallness of the crystals, their intimate mixture with the other alteration products, and the consequent difficulty, nay, impossibility, of complete separation, render a chemical analysis of the pure material out of the question, and their nature must, to a large extent, at least as far as the occurrences observed up to the present time are concerned, be determined on other grounds than chemical ones.

All the non-chemical means of investigation seem to me to point to the conclusion that these small reddish-brown crystals are in reality hypersthene, and the reasons for this opinion are now given. It must be premised that I do not regard the point as proved and the question definitely settled, the arguments I am proceeding to bring up going to show the great probability of the mineral being hypersthene, and not amounting to positive proof. The result of an unsatisfactory chemical analysis will be given later.

a. In the first place, the investigations of a number of observers * on melted hornblende show that on cooling (at least under the laboratory conditions chosen) it recrystallizes as augite. This is the unanimous result of all their experiments, and no case is known where hornblende recrystallized as hornblende. As Hyland pertinently says, "One cannot well explain theoretically how this tendency of melted hornblende to crystallize out as augite can be overcome." The results of the above-cited experiments seem to me also a strong ground for doubting the hornblende nature of the body in question, and for supposing it, on *a priori* grounds, to belong to the pyroxene group.

b. The pleochroism of the crystals agrees perfectly with that of hypersthene, which is given† as 𝔞 or *ă* brownish red, 𝔟 or *b̆* reddish yellow, 𝔠 or *ć* green. Hypersthene is usually elongated or prismatic parallel to *ć*, and taking the long axis of our crystals as *ć*, we find an absolutely identical pleochroism. Some of the crystals also show a tendency to become tabular parallel to *b*(010), judging from the pleochroism, which is quite frequent in hypersthene, but not the usual habit.

c. The constant parallel extinction observed by me (cf. Van Werveke, Doss, and Osann) points to a rhombic mineral, taken in connection with the pleochroism, and strengthens the idea that we have to do with hypersthene.

In contradistinction to my observations stands the almost unanimous testimony of the various observers that the mineral extinguishes obliquely. That this is a serious objection to the hypersthene theory I must admit; yet it can, I think, be explained in two ways. It must be remembered that in almost all the cases quoted the crys-

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* Mitscherlich and Berthier, Pogg. Ann. 1831, XXII. 338.

G. Rose, *ibid.*

Fouqué and Michel-Lévy, Synthèse des Minéraux et des Roches (Paris, 1882), pp. 61–78.

Becker, Dunkle Umrandungen der Hornblenden. Neu. Jahrb. 1883, II. 8.

Doelter and Hussak, Einwirkung geschmolzener Magmen. *Ibid.* 1884, I. 24.

Becker. Schmelzversuche mit Pyroxnen und Amphibolen. Zeit d. d. geol. Ges. XXXVII. 1885, p. 10.

Cf. Rammelsberg, Mineralchemie II. 394.

† Dana, Mineral. 6th ed. 1892, p. 349. Cf. Blaas, Jüngere Eruptivgesteine Persiens (Min. pet. Mitth., III., 1880, p. 482), and Hatch, Gesteine d. Vulcan Gruppe von Arequipa (*ibid.*, VII, 1886, 339).

tals are spoken of as being "very dark," or "almost opaque," and "only allowing of optical examination in thin parts of the slide." I conclude from this that the slides were relatively thick, especially in the case of the earlier investigators, and so the oblique extinction might have been caused by augite grains, unaltered hornblende, or particles of feldspar, lying above or below the brown mineral. It also seems possible that, unconsciously, a personal bias may have entered into the question; i.e., that the observers had the idea that the mineral was hornblende, and thought they saw an oblique extinction when it was in reality parallel. The illusion would have been heightened by the form of the crystals, which are often thicker at one end than at the other. However this may be, I can only say that, in my slides of the Kula basalts, the mineral was, in most cases, light colored, large, and well formed enough to admit of exact optical examination; that only such crystals were relied on; that they all extinguished parallel; and that this parallel extinction was observed and noted while I still thought the mineral hornblende, and before the idea of its being hyperstheue had occurred to me.

d. It will be remembered that in sections parallel to $\dot{c}$ of the hornblende most of the crystals are arranged parallel to this, with others crossing them at angles of 60°, while in sections perpendicular to the vertical axis the crystals are mostly perpendicular to the pinacoids and prisms of the hornblende. On the supposition that these crystals are hornblende in the latter case the arrangement can be explained as analogous to the network of rutile needles crossing at angles of 60° in mica; but for the other case no such explanation, based on the crystallographic properties of the host, can be given, the only important angles in hornblende near 60° or 120° being that of the prismatic cleavage, which would only affect the needles seen in horizontal section. The only twinning planes so far known in hornblende are $a(100)$ and $c(001)$, the latter giving rise to twinning lamellæ. Therefore, as we cannot find the explanation in the original hornblende crystal, we must look for it in the mineral itself; and here the hypersthene theory comes readily to our aid, and furnishes us with a good explanation. We find, in fact, that the dome (101) is a twinning plane of hypersthene, giving an angle between the two $\dot{c}$ axes of 60° 58′, it being also a twinning plane of the allied mineral enstatite. Becke * observed in andesite from southern

* Becke, Ueber Zwillingsverwachsungen Gesteinbildender Pyroxenen und Amphibolen. Min. Pet. Mitth., VII. p. 93.

Bukowina hypersthene needles twinned in accordance with this law, producing stellate forms, and he compares them with augite twins with the twinning plane *W* (122).

e. It has long been known that augite and hornblende tend to crystallize (when together) in parallel position—that is, with the $\acute{c}$ axes and the ortho- and clino-pinacoids parallel. Hypersthene has been observed* as an inclusion in augite in parallel position, and hence it can be inferred that it would also lie in parallel position in hornblende. This has, in fact, been observed by Hatch and Osann in cases cited below, and by Lacroix. If now we consider our mineral hypersthene, we find, by means of the pleochroism, that the crystals lying with their long axes parallel to the hornblende $\acute{c}$ have mostly their macro-pinacoids parallel to the brachy-pinacoids of the hornblende, as is also the case in the parallelism of pyroxene and hornblende.

f. The alteration of hornblende into hypersthene (along with other minerals) has been already several times recorded.† Hatch describes occurrences in andesites from the volcano Pichupichu near Arequipa, where the hornblende has become altered to a mass of feldspar, augite, hypersthene, and magnetite grains and crystals, the augite and hypersthene being in parallel position. Rudolph's and Lenk's examples are not as striking, while Osann refers the rhombic pyroxene observed by him to bronzite. It must be remarked that in all these cases of rhombic pyroxene as an alteration product of hornblende, it was also present in the rock proper.

g. On general chemical and mineralogical grounds it seems unlikely that, after the alteration of part of the hornblende to augite and magnetite, the rest of it should again crystallize as hornblende.

The above are my arguments in favor of the hypersthene hypothesis. As previously remarked, they are not held to be entirely conclusive, but as indicating a great probability. The subject seems a difficult one, but the difficulties have so far been chiefly those offered by the unsatisfactory nature of the occurrences. With

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* Bucca, Le Andesite dell' Isola di Lipari. Boll. R. Com. Geol. d'Italia, Nos. 9 and 10, 1885, p. 286. Lacroix. Sur Quelques Roches d'Arménie. Bull. Soc. Geol., 3d, xiv., 1891, p. 744.

† Rudolph, *op. cit.* p. 294 ; Hatch, Arequipa, pp. 352, 354 ; Lenk, Mexico, p. 17 ; Osann, *op. cit.* p. 688.

better material, which I hope to obtain, the question can undoubtedly be definitively settled.

In one of the hand specimens from the well-digging before referred to was found a dark spot, some two or three centimetres in diameter. On examination under the microscope this proved to be a mass of brown aggregate, magnetite, and some large augite crystals, with very little unaltered hornblende. It was thought that the brown crystals could perhaps be separated, and material enough obtained for chemical analysis, so the dark spot was reduced to a coarse powder, and the groundmass separated by means of Thoulet's solution. It was impossible thus to separate the brown mineral from the augite, and the brown mineral, as well as the magnetite, was attracted by the magnet. An attempt was therefore made to separate the magnetite by digestion with warm dilute HCl. Considerable iron was extracted, but it is to be feared that some of the brown mineral was itself decomposed, and hence the analytical results partially vitiated. However, an analysis of the resulting material was made with the following result, the alkalies not having been determined:

H_2O (Ign.)	0.50
SiO_2	49.00
Al_2O_3	7.78
Fe_2O_3	7.62
FeO	2.93
CaO	19.60
MgO	10.44
K_2O, Na_2O	——
	97.87

This result, it will be seen, is against the theory of hypersthene being present in any considerable quantity. For, hypersthene being a ferrous magnesium meta-silicate with a percentage of FeO, varying from 10.04 to 28.40 %,* we would expect in the material analyzed not only a much larger percentage of FeO than was found, but also that the quantity of FeO present would be greater than that of the Fe_2O_3. The very large percentage of CaO is striking, and seems only explicable on the theory that a much larger quantity

* Dana, *op. cit.* p. 350.

of augite was present than the microscopical examination seemed to show.

It is remarkable that this analysis is almost identical with analysis of augites from Kircheip and Naurod, and shows much resemblance to those of augites from the Vogelsberg and Greenwood Furnace.* I am inclined to say that much of the iron was lost through the treatment with HCl, though I must admit that this would not necessarily alter the relative proportions of ferrous and ferric iron, unless the ferrous iron present is more easily dissolved. It is much to be deplored that the result obtained is so unsatisfactory, but I hope on my next visit to Kula to obtain more appropriate material.

Theories of Alteration.—We are next confronted with the problem of the formation of this brown aggregate, and the augite-opacite aggregate, which has engaged the attention of many investigators, but which seems to be still in an unsettled and unsatisfactory condition. While agreeing with Hyland and Sommerlad as to the difficulty of the explanation, I think it worth while to examine the question and to offer my *quotum* toward its solution.

It must be remembered that we have two processes to consider, or, what is perhaps more correct, two stages of one process. It is true that in most cases of similar alteration of hornblende and biotite the formation of brown aggregate has not been observed (never in the case of biotite); but the evident close connection of the two methods of alteration in the rocks under discussion makes it seem probable that they are, at least partially, due to the same cause or causes. It is possible that one of the causes to be brought forward later may explain the difference in the two, but they will at present be discussed together.

It may be well to state first, in compact form, the various phenomena which must be explained by any theory proposed. The brown hornblende seems much more subject to these alterations than the green. The hornblende is generally, but not necessarily, changed first to a brown aggregate, and next to an augite-opacite aggregate; in the process some of the Fe_2O_3 being reduced to FeO. This change takes place first near the surface of the crystal and works inward, or else, especially in the case of the brown aggregate,

* Dana, *op. cit.* p. 360, Nos. 71, 72.

along cracks, and here without contact with the surrounding rock magma. The alteration, especially that to brown aggregate, often occurs without any change of form in the hornblende crystal. A layer of unaltered hornblende substance can be deposited on hornblende altered to brown aggregate, but it was not observed around the augite-opacite. The augite-opacite alteration is seldom, and the other never, met with in the plutonic or more acid volcanic rocks, and both alterations seem to be more common the less glassy the groundmass. The brown aggregate seems to have been formed at a comparatively early period.

We shall first state the various theories and ideas that have been advanced on the subject, as by a general view and comparison we can more readily determine what is of value and what may be rejected. It must be stated that the theories attributing this alteration to atmospheric action and decomposition, and the views that the magnetite, etc., are inclusions, are not considered, as numerous facts observed since their proposal have effectually disposed of them.

Zirkel,* as the cause of the formation of the augite-opacite border, says "that the dark opacite border is the product of the caustic-chemical action of the surrounding, still half-molten magma on the already crystallized hornblende crystals."

Rosenbusch, describing the so-called pseudomorphs of magnetite after hornblende and biotite, says †: "Such pseudomorphs appear to be conditional on resorption of the older porphyritical crystals, which, in certain stages of development of the magma, are not able to exist." In describing the dark border of biotite ‡ he remarks that it is less developed the more glassy the groundmass, "since here the solidification was completed before conditions could enter which would endanger the existence of the biotite." In another place § he attributes the alteration to the action of the magma during the eruption, there being at this period a great change in the chemical constitution of the magma, "and loss of water through sudden, or at least rapid, diminution of pressure, and the consequent considerable increase of its acidity."

* Zirkel, Ueber die krystallinischen Gesteine längs des 40te Breitgrades in Nordwest-Amerika. Ber. d. k. Sächs. Ges. d. Wiss. 1877, p. 197.

† Rosenbusch, *op. cit.* 3te Aufl. I. p. 285.

‡ *Ditto*, I. p. 583.

§ *Ditto*, 2te Aufl. II. p. 660.

Sommerlad,* after remarking that an explanation seems hard to find, goes on as follows: "Perhaps the original crystals were here melted, either only on the borders, or else completely, and the microlites were produced during quick cooling, and at the same time particles of the groundmass penetrated between them."

Petzold † speaks thus: "Perhaps one can form the following conception of their genesis [of the brown crystals]: The early crystallized hornblende underwent the solvent action of the molten magma, out of the solution there separated later augites, together with feldspar and the brown, hornblende-like mineral. From a chemical point of view there is nothing against this theory."

Siemiradzki ‡ thinks that "hornblende is produced in the depths in circumstances of strong saturation of the magma by superheated steam, and great pressure, while augite separates at the surface on cooling of the dry magma. The opacitic border of the hornblende crystals arises through action of the dry (freed from the crystal-forming H_2O vapor) molten magma on the crystals floating in it, while the augite is unacted on."

Lagorio § says: "The cause of the corroding action of the molten mass on the already crystallized ingredients is to be looked for, primarily, in the changed chemical composition, which the still fluid part undergoes through separation of successive generations of ingredients. But this change is not yet, it appears, enough for an effective assault on the already formed minerals. There is necessary for this still another circumstance." This other circumstance he takes to be the heat developed through diminution of volume on solidification, and he goes on: "This explains sufficiently well the frequent occurrence of opaque borders, and other corrosion appearances in crystals in rocks, in which, after separation of the primary ingredients, further crystallization took place."

Küch, ‖ after stating Zirkel's, Rosenbusch's, and Lagorio's views on the subject, admits that a corrosive action of the magma has undoubtedly taken place where the original contours of the horn-

* Sommerlad, *op. cit.* p. 150.

† Petzold, *op. cit.* p. 29.

‡ Siemiradzki, Geologische Reisenotizen aus Ecuador. N. Jahrb. Beil.-Bd. IV, 1886, 207.

§ Lagorio, Ueber die Natur der Glasbasis. Min. pet. Mitth. VIII, 1887, 462.

‖ Küch, *op. cit.* pp. 56, 57.

blende are more or less changed. He contends, however, that in the case of hornblende crystals which have preserved their original forms, and also where a separation of magnetite grains has taken place in the interior of the crystal, that no such corrosive action is possible. His explanation is that the alteration is due to a "simple action of heat."

Belowsky,* while admitting that Küch's theory explains many appearances, yet does not admit that it will explain all. "According to my opinion, the solvent and decomposing activity of the molten magma is to be put in the first rank."

It is seen on examination of these various theories that all the writers quoted, with the exceptions of Sommerlad, Petzold, Küch, and Belowsky, follow Zirkel in attributing the alteration to a corrosive action of the molten magma, differing in details, and in their explanations of the action. Exactly what sort of action this is supposed to be is not clear, though most seem to imagine a chemical reaction of some sort between the magma and the hornblende. Rosenbusch and Lagorio introduce certain physical conditions as necessary—the one diminution of pressure, the other a sudden rise in the temperature on solidification, the latter being also invoked by Sommerlad to account for the melting of the hornblende after solidification. Petzold and Belowsky both suppose a solution of the hornblende crystal by, and subsequent deposition of augite and opacite from, the molten magma. Küch, on the other hand, attributes the change entirely to the simple influence of heat, without fusion of the crystal.

Zirkel's explanation that the action of the molten magma is one of a "caustic-chemical" nature may stand as the general statement of this class of explanations, though the phrase is rather a vague one, and with no very definite meaning.

Lagorio rightly objects to Rosenbusch's theory that it is not clear what "Umstände" are meant, but that probably the quicker cooling in glassy rocks is thought of. He disproves this by an experiment of plunging a biotite crystal into a molten acid-and alkali-rich magma, and then allowing the mass to cool. The solid mass is perfectly glassy, but the biotite crystal shows in the section an opacitic border, though the action of the molten magma was almost momentary, The high percentage of SiO_2 (in this case *ca.* 69%) would seem to

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* Belowsky, *op. cit.* p. 45.

favor Rosenbusch's idea that the acidity of the basis has to do with the corrosion. Against this it may be urged that the Kula basalts are basic rocks with a percentage of silica of 47.5–48. We learn from some analyses of basalt and their glass bases by Lagorio* that the difference in acidity of a basic rock, poor in alkalies, and its glass basis is practically nothing, in two cases the glass being even slightly more basic than the basalt. It is therefore safe to assume that the glass basis of the Kula basalts—and hence the molten magma at all stages—was a basic one, and yet we have here the alteration extremely well marked and very constant.

An objection to Sommerlad's theory is that one would expect, in accordance with his idea of quick cooling, to find the brown crystals, and augite and opacite grains, as frequently in the very glassy rocks as in the less glassy, which we know not to be the case. Petzold remarks that this theory is forced, and justly says that if this were the case one would expect to find the microlites, and so forth, in the neighborhood of such altered hornblende crystals, which we do not. This objection would also lie against Petzold's theory itself, against which perhaps no chemical objection can be brought, but grave physical ones. But it seems to me that the strongest argument against these or similar theories involving a fusion or solution of the hornblende crystal is the fact that so many cases occur where the hornblende is altered in substance and yet not in form. One cannot say that in the one case the alteration in substance is due to one cause and in the other case to another, as Küch seems to do, since the alteration product in both is identical, but we can logically attribute the alteration of substance and alteration of form to different causes. To me it is impossible to conceive of any body preserving its sharp outlines if existing in a fluid or semi-fluid state in a moving molten magma; and that the magma was in motion after (and hence during) the alteration is shown by the fluctuation structure of the microlites about all the larger altered crystals. That after the solidification of the surrounding magma the hornblende could have become fused without losing its form is posble, but that such should happen before solidification of the magma I hold is impossible. Belowsky exclaims, "Why should not the sharp contours of the crystals be retained on a solution of the hornblende and immediate separation of augite- and ore-grains?"

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* Lagorio, *op. cit.* p. 479.

But it seems to me much more proper to ask, Why should they be retained? Such an occurrence would run counter to all our experience. The idea also of *immediate* separation of augite and magnetite which he has to suppose, and which Sommerlad is also compelled to bring in, seems decidedly forced, unnatural, and unnecessary. So I shall exclude from consideration as an explanation of the alteration of substance any fusion or solution of the crystal, as being not in accordance with the observed facts. The change of form often seen, in some cases very profound and amounting to a complete scattering of the altered crystal through the rock substance, is not necessarily due to fusion, but is much more probably simple mechanical disintegration, the granular pseudomorph not being as coherent as the unaltered crystal.

Siemiradzki's view that the hornblende was formed at a considerable depth under conditions of great pressure and saturation of the magma with superheated steam seems to me to have much to recommend it. It is chiefly based on the fact that so far we have been unable to produce hornblende under conditions of *dry* igneous fusion, while augite is readily so produced.* I cannot, however, agree with him in regard to the period of formation of the augite. In the Kula basalts the augite is frequently an inclusion—often in large crystals—in the hornblende, this being much more often the case than the converse. Indeed part of the augite seems to have been formed at the same time as, if not before, the hornblende, and the formation of the two apparently went on hand-in-hand for some time, the formation of hornblende finally ceasing, while that of the augite as microlites still continued. It is perfectly possible that augite may be formed in a moist molten magma as well as in a dry one. His explanation of the cause of the alteration is a general one and, with the exception of the magma being supposed dry, apparently identical with Zirkel's. An objection to his theory that the alteration is dependent on the *dryness* of the magma lies in the fact that steam is usually present in the lava when it reaches the surface, and hence the magma is hardly ever in his supposed waterless condition. This objection, however, lies only against his explanation of the alteration, not of the formation, of the hornblende, his view of the latter seeming to me to be a very probable one.

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* Cf. Fouqué et Lévy, Synthèse des Minéraux et des Roches, p. 102.

That Lagorio's "changed chemical constitution of the magma" due to loss of some of the constituents as minerals crystallized out is not always a necessary condition, seems to be shown by the fact that zones of unaltered hornblende are seen around altered substance. The rise in temperature due to solidification—which has in fact been observed *—may enter as a factor, and will be spoken of again.

To sum up: Though the process under discussion is strictly a chemical, or physico-chemical, alteration, yet, as crystallization of the newly formed bodies takes place, it may, I think, be justly assumed that factors of simple crystallization would also play a rôle in the present process.

Michel-Lévy† gives the three factors of temperature, pressure, and mineralizing agents, as bringing about crystallization in molten magmas. He further remarks that in basic rocks pressure and mineralizing agents are of little importance, and the minerals we can ascribe to them—biotite and basaltic hornblende—are rare in basic magmas, and in the last phases of rock formation are often absorbed and changed to augite and magnetite.

Iddings‡ in an able paper gives the following list, the factors being arranged in the order of their importance:

> "*Cooling*, and a certain amount of
> *Time*, or the *Rate of Cooling*.
> *Chemical Composition* of the magma.
> *Mineralizing Agents*.
> *Pressure*."

Some, or all, of these may enter into the problem, and I would further propose two additional ones.

But we must now take up for consideration the two modes of alteration separately, as the conditions of the formation of the two aggregates produced are evidently not quite the same. We will first consider the brown aggregate, as this is the first formed, and, to a certain extent, leads to the other.

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* "Scacchi, Palmieri, and Guarini observed this phenomenon during the eruption of Vesuvius in 1855 in the lava of the Fossa della Vetrana. Cf. Roth, Der Vesuv und die Umgegend von Neapel. Berlin, 1857, pp. 293 and 304." Note in Sommerlad, *op. cit.* p. 142.

† Michel-Lévy, Structure et Classification des Roches éruptives. Paris, 1889. pp. 5 and 9.

‡ Iddings, On the Crystallization of Igneous Rocks. Bull. Phil. Soc. Washington, XI. 1889, pp. 106, 113.

For the formation of this (the brown aggregate) I would introduce a factor, the effect of which seems, heretofore, to have been unrecognized, namely, the chemical action of gas occluded, or otherwise present, in the molten magma. Hydrogen is, of all gases, the most easily occluded by a molten magma, and that it is abundant in the gases given off during eruptions is well known. Its presence is undoubtedly due to the dissociation of water at the high temperature of the fluid lava. If we adopt Siemiradzki's theory we must suppose that the crystallization of the hornblende started at a considerable depth, when the lava was saturated with water vapor, due to the ingress of water which started the eruption. As the lava ascends the conduit this water vapor becomes partially dissociated, the dissociation of steam taking place gradually, as shown by experiments. Whether Siemiradzki's theory is correct or not, hornblende is present (as shown by the broken and distorted crystals) in the moving mass of magma containing occluded hydrogen at a high temperature. This hydrogen, occluded and hence in close molecular contact with the ingredients of the mass, would exert a powerful reducing action on the hornblende (which seems especially subject to certain forms of alteration), reducing the Fe_2O_3 to FeO, with the production of hypersthene, magnetite, and some augite. The hydrogen, it will be observed, could penetrate crevices that the molten magma would be unable to do, and so account for the frequent alteration we observe in such places. That this action should take place only in basaltic rocks seems at first, perhaps, an objection. But when we remember that it is almost solely in these rocks that brown hornblende occurs, that this variety is the only one that contains Fe_2O_3 to a large extent, and that in the Kula basalts, as well as in other instances, this is the only variety altered, the green generally remaining unchanged, we have, I think, found the explanation. It is only in these rocks that the hornblende contains iron in a reducible condition. It would seem from this that it requires the reduction of Fe_2O_3 to FeO, and not merely the presence of FeO, for the formation of the brown (hypersthene) aggregate. In this alteration it would seem that the chemical constitution of the magma may be left out of account as a direct factor, it having, of course, to do in the first place with the formation of a brown hornblende rather than a green. However this may be, it is certain that a high temperature is necessary, not only for the dissociation of the water, but for the reducing action of the resultant hydrogen. That pressure is necessary seems probable, but of this we cannot be certain. It will have been noticed that for all this process no fusion or solution of the hornblende is necessary, and hence the crystal may retain its shape and sharp edges, as we find to be the case. As the dissociation of water begins at a temperature considerably above that of the melting-point of basalt, at a higher point of the conduit much of the dissociated hydrogen and oxygen would recombine, producing a moist magma, and hence, through the absence of free hydrogen, preventing further alteration, and allowing the production of fresh hornblende, which would either be deposited on the already altered crystals, or else separate out as smaller crystals.

The formation of an augite opacite aggregate is a different, and perhaps a simpler, process. It must be borne in mind that, as shown previously, it invariably takes place at a later stage than the alteration into brown aggregate.

Of Iddings' list of factors given above we can safely eliminate those of pressure and mineralizing agents, on the ground of Lagorio's, Becker's, and Doelter and Hussak's experiments, which show that hornblende can be altered to an augite-opacite aggregate under ordinary atmospheric pressure, and in a dry magma, without the presence of mineralizing agents. In this I am at one with Michel-Lévy, though, as will have been gathered from foregoing remarks, I cannot admit the *resorption* of hornblende, in this case.

It would perhaps seem reasonable to exclude also the chemical constitution of the magma, since we find the same alteration taking place in acid and basic, and alkali-rich and alkali-poor, magmas. Against this can be urged the undoubted fact that the alteration is more frequent in the basic vulcanic rocks. Perhaps an explanation similar to that brought forward for the same factor in the brown-aggregate formation could be found, but at present it seems best to retain this factor, though with some hesitation.

That a high temperature is necessary is certain, but that the rate of cooling enters in is rather doubtful, since arguments can be brought forward on both sides. However, on the ground, chiefly, of the more frequent occurrence in the less glassy rocks, it must I think be retained, though, like the preceding, with some hesitation.

Into this process I would also introduce a new factor, a molecular change similar to that occurring in many bodies under certain conditions, as the change of monoclinic to orthorhombic sulphur, and that of many organic compounds into isomers or polymers. I suggest then that this alteration is due to a chemical action of the magma—the nature of which is not very clear—on the hornblende crystal, either unaltered or changed to brown aggregate, in the latter case the brown mineral (hypersthene) alone being affected. This obscure chemical action is aided, or perhaps superseded, by a molecular change going on in the crystal itself due to a long-continued high, but gradually diminishing, temperature, or a slow rate of cooling. This molecular change splits up the hornblende molecule, the ferrous and ferric oxides present going chiefly to form magnetite and the CaO and MgO forming (with a small proportion of the iron) a colorless pyroxene, which is probably a diopside. It seems probable that the composition of amphibole is a more complicated one than that of pyroxene, and "Tschermak* has shown reason for writing the amphibole formulas as double the corresponding ones for pyroxene." It is also to be seen that the formula of an aluminous hornblende containing Fe_2O_3 is more complicated than that of a (probably) non-aluminous pyroxene containing little or no iron. Hence the molecule is much more readily split up, and subject to alteration under conditions which would not affect the augite molecule. The same reasoning applies in the case of the brown aggregate alteration.

The above explanation of what is, it must be confessed, a difficult subject is roughly given, and may not be completely satisfactory. Still it seems to me to be fully as reasonable as, and more definite than, any of the theories heretofore proposed, and gives an explanation for all the observed phenomena. My time and space do not permit me to go into the details of this last point, or to enter into a longer discussion of the subject, but enough has, I think, been said to make the theory clear, and the reader can follow out its application at his leisure.

Olivine.—One of the characteristic features of the Kula basalts is the relatively small quantity of olivine present, which, while very constant in its occurrence, forms but a very small proportion of the component minerals. It is always, like the hornblende, porphyritic. The largest olivines vary from 0.5–3.0 mm. and are nearly all fragmentary. The smaller crystals vary from 0.05–0.4 mm. in length by nearly the same in thickness, and are, in contradistinc-

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* Tschermak, Min. pet. Mitth. xxxviii, 1871. Cf. Dana, Miner. p. 388.

tion to the larger, usually well formed. They show the planes *a*(100), *b*(010), *m*(110), *d*(101), and *k*(021). Frequent rectangular sections are seen, indicating the absence of prisms or domes on many of the crystals. Though the largest olivines are bright greenish yellow as seen macroscopically, in sections they are both colorless and are remarkable for their perfect clearness and freedom from alteration. With the exception of two specimens from Aï Tepesi, where the olivine is colored a clear reddish yellow on the border, the olivine is without a trace of decomposition of any sort. This freshness of appearance and the colorlessness, taken together with the imperfect way in which the augite shows its cleavage, rendered it a matter of great difficulty at times to distinguish the two minerals.

Though the smaller olivines are, as a rule, well formed, yet here and there peculiar forms due to irregularities of growth and development, to which olivine is very prone, were seen, in some cases the angles being developed more than the faces. What is probably due to a similar cause is shown in Pl. III., Fig. 5, though it may be a corrosion phenomenon. There we have a section parallel to *a*(100), showing the brachypinacoid *b*(010) and the dome *k*(021). It is seen that the angles are sharp, while piercing all the domes are holes leading to shallow cavities filled with groundmass. The bottoms of these cavities are not flat but convex, and their comparatively great width and narrow mouth are very striking. A crystal similar to these is seen in the sideromelan nucleus of a manganese nodule from the bed of the South Pacific.* Another inclusion form which seems to be a consequence of growth is shown in Fig. 6. Here two large spots of clear brown glass are seen at each end of an olivine crystal. This arrangement, which is quite often met with, is probably due to the formation of a crystal forked at the two ends, as is so common in olivine, the filling of the open spaces with groundmass—at that period apparently free from microlites or magnetite—and the subsequent growth of olivine substance beyond and around them, completing the crystal form, and isolating the two masses of glass. In another case (Fig. 7) a hexagonal section is seen with four bands of brown glass lying parallel to the prisms, and in still another we have a lozenge-shaped section of

* Report of the Voyage of H.M.S. "Challenger": Deep-sea Deposits. London, 1891. Pl. XVI., Fig. 1.

olivine, about this a zone of ground mass, and about this again a shell of olivine of the same shape as the core (Fig. 8). Inclusions are, however, not very common and are mostly of brown glass or groundmass, each crystal containing but one or two. They are occasionally relatively large, and are also sometimes of the same shape as the host.

Besides these glassy inclusions there were seen two olivine crystals containing peculiar trichite inclusions, such inclusions being, it may be stated, of rare occurrence in basaltic hornblende. The first is in a hyalopilitic basalt from one of the knolls, and is shown in Fig. 9. Here there are two olivine crystals, one 1.2 × 0.4 mm. and of rectangular outline, and another of about the same size, but broken, adjoining it. In these are seen very fine, hair-like black lines, which by the aid of high powers are resolved into rows of extremely minute black grains, sometimes looking as if strung along a fine black hair. In the larger crystal these margarites do not lie irregularly, but the majority of them are perfectly straight and parallel to the long sides of the crystal, often curving about at the ends so as to enclose an oblong space. In the broken crystal they are mostly curved, and do not lie as regularly, but still are generally in groups of individuals parallel to one another. At the junction of the two crystals is a narrow black border on each, from which many small trichites emanate.

The second case, occurring in the upper scoriaceous part of a "knoll," is of an olivine crystal, 0.55×0.45 mm., shown in Fig. 10. It is of an ovoidal shape, with flat ends, and is sharply divided into two parts along a line running across it at its widest part. The larger half shows a colorless mass of olivine, containing numerous coarse black lines, which can be readily resolved into rows of black grains. These margarites are all curved and lie in groups of members parallel to one another. The smaller half looks under low powers almost perfectly black and opaque, but the higher powers show it to be also made up of colorless olivine substance, with numerous black grains and trichites, mostly arranged in parallel straight and curved lines.

Both these occurrences resemble the trichite inclusions in the olivine of a gabbro from Mull described and figured by Zirkel.*

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* Zirkel, Mikroskopische Beschaffenkeit de Mineraliern (Leipzig, 1873), p. 214. Cf. Renard, Petrol. Ocean. Islands (London, 1889), p. 57.

The olivine also frequently shows signs of corrosion, which has generally acted irregularly, forming deep bays and pockets. In many cases the original outline has been entirely lost and only a small part of the original crystal is left. It also happens that one end of a crystal will be perfectly unacted on and show sharp angles and straight lines, while the other end will be deeply eaten away. All these appearances are so common and have been so often described and figured that it was not thought worth while to illustrate them.

One special case, which may however be due to growth, is here shown (Fig. 11). It is a rectangular section, 0.2 × 0.14 mm., from one angle of which runs a small prolongation of the side. This extinguishes exactly like the body of the crystal and is not an adhering fragment.

Magnetite.—This occurs both in the groundmass and, as already described, as an alteration product of hornblende. In size the grains vary from 0.005–0.03 mm., a few attaining a diameter of 0.1 mm. when the sub-metallic lustre in reflected light is easily seen. These large grains are irregular in shape, but the smaller ones frequently show sharp outlines, representing sections of octahedra.

A very interesting observation was made in regard to its occurrence in the groundmass, which has an important bearing on the question of its period of formation. It will be remembered that the Kula basalts can be divided as regards their structure into normal, hyalopilitic, semi-vitreous, and tachylytic varieties, and it may be further stated that all these varieties possess practically the same chemical composition.

In the first two types—the least glassy—the magnetite is very abundant and the glass basis colorless. In the semi-vitreous variety the magnetite is only sparingly present and the glass basis a light cinnamon-brown. In the tachylytes—which are almost pure glass—the magnetite is almost entirely absent and the glass a dark chocolate-brown.

Here we have a beautifully shown transition series, the magnetite content varying inversely as the glass content and as the depth of color of the glass basis. This seems very good proof that the magnetite is, in these basalts, not one of the first minerals to crystallize out as is generally held to be the case,* but that it was among,

* Cf. Rosenbusch, *op. cit.* 3te Aufl. I. 287., II. 342. It is interesting to note

if not quite, the last. The facts that magnetite is very rarely seen as an inclusion in the other minerals,* and the numerous inclusions of clear brown glass, point the same way.

It may be objected that an explanation of this lack of magnetite in the more glassy basalts is to be found in a reabsorption by the magma. This, however, seems forced and impossible, it being difficult to explain a reabsorption in the quickly cooled-rocks, while such an action did not take place in the slowly-cooled ones. It has also been pointed out by Iddings † that the first mineral to separate out is the last to be reabsorbed, and *vice versa.*

The above observations are quite contrary to the generally held views on the subject of the relative age of the magnetite in a given rock, but there can be no doubt of the facts stated. They form one of the prominent characteristics of the whole series of slides, and hardly an exception was to be found to the general rule. It may be mentioned that Vogt has shown in a recent work‡ that in the case of some slags the magnetite is crystallized out after the olivine.

Leucite.—This mineral was observed only in the lava of the northeast and southeast streams, and in only one specimen of lapilli from the crater of Kula Devlit out of half a dozen examined. The crystals are all small, from 0.05–0.3 mm. in diameter, perfectly colorless, and only occasionally show anomalous double refraction. The outlines are generally rounded, but here and there some distinct octagonal sections are seen. They contain, as usual, microlitic inclusions of augite and magnetite, the former being much the more common. These augite microlites are generally arranged in one or two rings, concentric with the outline of the crystal, while the magnetite is more irregular. A few are seen with a nucleus of dusty opaque grains occupying the centre of the crystal, and an augite-microlite ring surrounding this. These resemble the leucites in a leucite-basanite from Kilimandjaro described by Hyland.§

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that Judd (Scot. Gabbros, Q. J. Geol. Soc. 1886, 79) observed exactly the opposite state of affairs in the basalts of western Scotland.

* The magnetite which occurs as an alteration product of hornblende is, of course, not referred to in this connection.

† Iddings, Crystal. Ign. Rocks, *loc. cit.* p. 105.

‡ Vogt, Mineralbildung in Schmelzmassen (Kristiania, 1892), p. 210.

§ Hyland, *op. cit.* p. 261.

The occurrence of leucite in connection with hornblende basalts is interesting, the combination never before having been observed. It may be also mentioned that this is only the second recorded occurrence of leucite in Asia Minor, La Croix * having observed it in rocks brought from Trebizonde, and which he identified as leucite tephrites and leucitites. These leucite rocks seem to have their eastern continuation in Persia.†

Apatite.—This was only seen once or twice in the second-period basalt from a well-digging in Kula. In this rock hexagonal sections were observed, about 0.1 mm. in diameter, pale gray in color, and with lines of very fine dust-like grains crossing each other at angles of 60°. These few crystals, however, are not integral parts of the rock, but are undoubtedly derived from enclosures of foreign rock brought up from below. One such enclosure of plagioclase containing many identical apatites was seen in the same slide.

The rather large percentage of P_2O_5, in one case 0.97%, equivalent to about 2.5% of apatite, is to be explained on the supposition that some of the microlites present in the groundmass are in reality apatite. Many of them do extinguish parallel to the long axis, but also many obliquely. The latter may be considered augite, and part of the former apatite.

Melanite and Spinel.—Only three crystals of the former were found; one, 0.01 mm. in diameter, in the groundmass of a hyalopilitic "knoll" basalt, and two smaller crystals as inclusions in a large augite, in a specimen from the northeast stream. They are all dark brown in color, with high relief. All three are almost undoubtedly derived from inclusions which have been altered by contact with the basalt, and do not form essential ingredients of the rock. A few crystals of green spinel were seen in the groundmass, but they are so evidently derived from enclosures of foreign rock that further remarks on them will be deferred to a later page.

Biotite.—Two crystals of dark-brown biotite were seen, both undoubtedly derived from foreign rock. One, in a glassy knoll basalt, is a brown crystal fresh in the interior but altered in the outer part to a border of augite and opacite grains, and a brown

* Lacroix, Sur les Roches à Leucite de Trébizonde. Bull. Soc. Geol. de France, XIX, 1891, p. 732.

† Steinecke, Leucitbasalte u. a. Leucitgesteine in Persien. Z. f. Naturwiss. Halle, 4, VI, 1887, p. 1.

mineral which looks extremely like the brown mineral found in the hornblende. The crystals are similar in shape, but the pleochroism is not as well marked here, and the two colors observed were dark brown parallel to the long axis and light brown at right angles to this. The extinction was parallel. I think it probable that these crystals are the same mineral as in the hornblende, and if so it will be the first case in which it has been found in biotite. The second biotite crystal was in the lava of Kara Tepé, dark brown, and showed no signs of alteration. Here the rock was more glassy than in the other case.

General Description of Basalts.

Having described the various minerals that enter into the composition of the Kula basalts, we may now take up the general description of the rocks from the various localities, and for this purpose an arrangement in accordance with their chronological succession, as far as is possible to determine it, will be the best to follow. As I did not collect any specimens of the basalts of the first period, we shall pass that over and begin with the—

Second-period Basalts.—These are represented by specimens from a well-digging in the northeast part of the town of Kula, from the eastern slope of Aï Tepesi, from the end of its southeast lava stream, and from the second-period stream which underlies the northern Kula Devlit stream, at the Gediz Bridge. The well digging is, according to my host, about 35 metres deep, sunk through lava, and the specimens obtained came from the lowest level whence they had been newly dug. Below the lava they find "baked earth," and strike water some 10 metres down in this. This lava is of sp. gr. 2.733, rather rough in texture, but fine-grained, with few gas pores, and perfectly fresh. Its color is light ash-gray, and scattered through the rock are seen greenish-yellow, glassy, augite and olivine phenocrysts, but very few hornblende phenocrysts. The other specimens of this period are similar, except that they are more compact and the Aï Tepesi ones darker. The sp. gr. of the piece from the slope of the cone is 2.813, and of that from the end of its lava stream 2.721. This last lava showed a lamellar structure resembling that of phonolite.

Under the microscope they are all seen to belong to the "normal" basaltic type, the groundmass being a mixture of colorless glass and leptomorphic feldspar, with quite abundant colorless augite microlites, plagioclase laths and magnetite grains, which often show a fluctuation structure. The porphyritical generation is represented by augite and olivine in generally small crystals, and hornblende. The last is in all these rocks most completely altered, not a particle of unaltered hornblende having been seen. The crystals have all gone over either into a mass of brown aggregate surrounded by an augite-opacite border or, most frequently, completely into a mass of augite and opacite grains, with very commonly a ring of larger opacite grains near the edge. (Cf. Pl. IV, Fig. 2.) The form of the crystal is not as well preserved as in the later lavas, and most of the smaller crystals have been reduced to rounded forms. The relative proportion of glass is not as great as in any of the later rocks, and this, the larger-grained structure, the leptomorphic feldspar, and the perfect alteration of the hornblende may serve to distinguish the basalts of the second period from those of the third. The chemical composition is shown in Analysis I, page 57.

Third-period Basalts.—We shall take up first of these the basalts of "*The Knolls.*" The lava of which these are composed presents three distinct types of structure, which show a gradual transition into one another, they being all glassy. These three types may be called hyalopilitic, semi-vitreous, and tachylytic.

a. Hyalopilitic.—These are all dark iron-gray rocks, of a very compact texture, and with few or no gas pores. The sp. gr. of one of them is 2.704. Scattered through the mass of the rock are numerous small, glistening, black hornblende phenocrysts. while augite and olivine are seldom to be seen. Rounded grains of clear colorless quartz enclosures are not uncommon, one of these having a length of 15 mm. A few feldspar enclosures are also to be seen in the specimens examined, and one much-decomposed piece has cavities filled with a white zeolitic mineral. This piece is decomposed on the surface to a dull chocolate brown mass, and veins of the same color are seen running through it. The large majority of the specimens, though, are quite fresh and unaltered.

Under the microscope these rocks show a highly typical hyalopilitic groundmass, of which the basis is a colorless glass. This is very thickly strewn with small plagioclase laths, colorless microlites, and magnetite grains, the last two being especially abundant. In addition to these is also seen a considerable quantity of black straight trichites. In some places the groundmass is colored brown in long streaks which run though the colorless mass. A fluidal arrangement of the plagioclase laths and augite microlites, especially about the large phenocrysts, is not uncommon, but not as well developed as in the more glassy varieties to be next described.

Phenocrysts are quite abundant, consisting of hornblende, augite, and olivine. The hornblende is generally brown, these rocks being quite deficient in the green variety. The hornblende is almost invariably altered, but generally only as far as the second stage, where brown aggregate and a narrow augite-opacite border surround a core of still unaltered substance, and the outlines are well preserved. The augite and olivine present no special features of interest. For chemical composition see Anal. II, page 57.

b. Semi-vitreous Type.—In this type of the knoll basalts are included two specimens from the "ropy" stream east of Kara Tepé, which is considered to belong to the same period on the ground of the character of its flow, and its great resemblance under the microscope. These rocks are all iron-black, occurring both in compact and somewhat vesicular varieties, the pores of the latter being small and not very abundant. They have not the dull lustre of the preceding rocks, but present a rather shining fracture, with a pitchy sub-resinous lustre. The sp. gr. of one is 2.647. As phænocrysts are seen many small glistening black hornblende crystals, which, as well as the pores, are arranged in lines of flow. Crystals of augite or olivine visible megascopically are very rare. Though some of the specimens are decomposed on the surface, yet at a depth of a few mm. they are perfectly fresh, moisture apparently not having been able to penetrate at all.

Microscopically these rocks show a largely preponderating light cinnamon-brown glass basis, often mottled light and dark, and occasionally with streaks of a much darker color. In this glass basis are many augite microlites, plagioclase laths, and magnetite grains, the microlites being by far the most abundant, while the magnetite is present in very much smaller quantity than in the preceding. The bearing of this fact on the crystallization period of the magnetite has been already discussed. The plagioclase crystals, while fewer in number than in the hyalopilitic variety, are rather larger and better developed. The black trichites seem to be entirely wanting. The microlites and plagioclase crystals show frequent fluidal structure. (Cf. Pl. IV, Fig. 1.)

The phenocrysts are hornblende and augite, with only rarely olivine. The hornblende is commonly brown, but green crystals are also seen. Both are usually fresh, and when alteration has taken place it has nearly always only reached the brown-aggregate stage. The augite is in small colorless and very bright crystals, fairly well developed, An analysis of this type was not made, but compare Analysis VI. of a Kara Tepé lava, which very closely resembles this type.

c. The tachylytes* occur chiefly as streaks in the semi-vitreous lavas, often forming the upper surface, but one "knoll" was composed almost entirely of this variety. They are very compact jet-black rocks, with a vitreous lustre. In some places they have acquired through slight surface oxidation an iridescent tarnish, which, with their color and lustre, gives them an anthracitic appearance. The sp. gr. of two specimens was found to be 2.695 and 2.747. The latter is strangely high for so glassy a rock, and a mistake is possible. As crystallizations are to be seen microscopically a few small black hornblende crystals, and very rarely a small augite. One specimen contains on the surface a few spots of white zeolitic mineral, and a small quartz enclosure.

Under the microscope they are seen to consist almost entirely of a clear dark chocolate-brown glass, with streaks of a darker and dusty material which show the fluidal structure very finely. There are also present a few augite microlites, very few small plagioclase and augite crystals, and streaks of dark dusty-brown material which aid in bringing out the fluidal structure. Magnetite is practically entirely absent, and no perlitic cracks are seen. As phenocrysts there are present hornblende in rather large crystals, both brown and green, often showing zonal structure, but always clear and unaltered. Large crystals of colorless augite, but very little olivine, are also present. These rocks on the whole are beautiful examples of tachylytes, and form some of the prettiest slides of the series. An analysis of one is given in No. III, page 57.

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* They are decomposed by hot HCl with separation of gelatinous silica on cooling, and so are true tachylytes.

Southwest Stream.—This stream is composed of a dark ash-gray, very compact and tough basalt, showing few or no pores. The sp. gr. of one specimen proved to be 2.613. A few very small hornblende crystals and still fewer augite-olivine crystals are to be seen, and the specimens are all perfectly fresh.

Under the microscope they are all, with one or two exceptions, of the regular hyalopilitic structure, with a colorless glass basis. Microlites and magnetite grains are very abundant, the plagioclase less so. The hornblende is dark brown and most of it has undergone alteration to brown aggregate, occasionally having reached the last stage. The remarks made under the head of the hyalopilitic knoll basalts apply equally well here, as the rocks seem almost identical.

The two exceptions above spoken of belong to the semi-vitreous type, with brown glass basis, and are like the corresponding knoll rocks except for one peculiarity. This is the presence of spots of colorless glass, from 0.1–0.3 mm. in diameter, generally round in shape, but often quite irregular. These spots contain, besides microlites and magnetite grains, many straight black trichites, which are commonly arranged in a roughly radial manner. This colorless glass is surrounded by a ring of brown glass much darker than the rest of the groundmass, but shading gradually into it, and containing the usual groundmass microlites, etc. These spots might be mistaken for leucite, but their size, the irregularity of their form, the fact that plagioclase needles were seen lying both in the colorless glass and in the brown ring, and the brown ring itself all show that they are not leucite. Hatch * observed and figured similar objects from a Madagascar basalt. They are apparently due to small local development of iron-rich black trichites, with concomitant repulsion of the unused iron from their midst, forming the ring.

North Stream.—This and the following stream offer a special feature of interest inasmuch as they are both leucitic. The rock of which this stream is composed is light gray and compact, but mostly with numerous small gas-pores arranged in streaks, showing the flow structure. The sp. gr. of one specimen is 2.711. Practically no hornblende is to be seen macroscopically, but augite and olivine phenocrysts are abundant.

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* Hatch, Rocks from Madagascar, *loc. cit.* p. 350.

Under the microscope they show a hyalopilitic structure, the glass basis being always colorless. Microlites and magnetite grains are very abudant, but plagioclase is rare compared with the preceding hyalopilitic rocks. These small bodies frequently show a fluctuation structure, especially around the large phenocrysts.

These phenocrysts are hornblende, which is always altered, generally to the last two stages, augite and olivine in clear colorless crystals and fragments, and leucite, which is quite abundant in streaks and patches. The crystals are small, but very characteristic and unmistakable. The description given farther back covers all the points of interest, so nothing further need be said here. Analysis IV shows the composition of these rocks.

Southeast Stream.—This stream, as before mentioned, seems to be made up of two distinct streams, one above the other, which have been poured out since the period of the knolls, the lower one being more compact and with a tendency to columnar structure. However, as the two seem identical petrographically, they will be described together, a few words sufficing, as they greatly resemble the rocks of the north-stream. These rocks are dark gray, those of the lower stream quite compact, those of the upper vesicular. They show few crystals of hornblende, but macroscopic crystals of augite and olivine are rather abundant. Three different specimens had sp. grs. of 2.712, 2.715, 2.736.

Microscopically they are hardly to be distinguished from the north-stream basalt, being of the same hyalopilitic structure and containing leucite in addition to the usual constituents. The leucite calls for no special comment, exactly resembling the occurrence just described. Analysis V is of a specimen from this stream.

Kara Tepé Stream.—Specimens were collected from the well-defined lava stream of Kara Tepé at three different points: at the bottom of the crater, at a point about one hundred metres down the stream, and again some fifty metres below this. No difference however, is to be seen among them, either megascopically or microscopically. They are all iron-black compact rocks with numerous fine pores and a sub-greasy lustre. The sp. gr. of one is 2.604. Small shining black hornblendes are very abundant, and are generally arranged in lines of flow. Augite and olivine are rarely seen.

Microscopically they show a groundmass of light, unmottled, cinnamon-brown glass, with numerous colorless augite microlites, some magnetite grains, and not very abundant small plagioclase crystals. These last are much larger than usual and better crystallized. They nearly all show twinning lamellæ, and it was in these rocks that optical investigation of the plagioclase was possible. Otherwise the groundmass resembles closely that of the semi-vitreous knoll basalts.

The phenocrysts are mostly hornblende, which is here frequently green, these rocks being far richer in this variety than any of the others. The hornblende is generally unaltered, but when such is not the case the alteration generally only reaches the brown-aggregate stage, with a kernel of hornblende. The augite and olivine are not common, but in these rocks the hour-glass and similar structures are very common among the augites, most of them showing phenomena of the sort. The chemical constitution is shown in Analysis VI.

Scoriæ.—Specimens of scoriæ and lapilli were collected from the craters of Kula Devlit and Kara Tepé. They are generally black, but sometimes red or brown from decomposition. They are, of course, very vesicular and spongy. Megascopical crystals are rarely to be seen.

They all show under the microscope a basis of dark-brown—occasionally red-brown—glass containing many augite microlites and plagioclase laths. Magnetite is very rare, but occasionally a fine brown "dust" is present. Hornblende occurs in large crystals both brown and green, frequently zonally colored, and often showing the alteration to a dark red-brown variety. Augite and olivine crystals are also present, and in one specimen from Kula Devlit leucite, in crystals exactly resembling those described above, was found. It was noticed that the inner surface of many of the vesicles was coated with a thin layer of colorless or light-yellow substance, which showed in some places a weak aggregate polarization.

Chemical Analyses.—The analyses on p. 57 were made for me by Dr. A. Röhrig of Leipzig.

From these analyses it will be seen that these rocks belong to the more acid basalts and that they show a most marked similarity with one another. The composition is a normal basaltic one, the SiO_2 being rather high, the Al_2O_3 (also in rather high percentage) coming next in relative amount, the percentage of MgO being less than that of CaO, and that of K_2O less than that of Na_2O. The generally high percentagetof Na_2O points to the presence of nepheline, but treatment of some of the slides with acid gave negative

	I.	II.	III.	IV.	V.	VI.
H_2O (Ignit)....	0.02	0.46	0.12	0.48	0.04	0.30
SiO_2...........	48.24	47.50	47.79	47.97	47.74	47.58
Al_2O_3..........	20.64	19.82	18.52	20.04	20.95	20.36
Fe_2O_3..........	4.63	4.75	4.65	4.45	3.29	3.78
FeO..........	5.55	5.20	5.47	5.50	6.32	5.45
CaO...........	7.94	8.37	8.34	7.64	7.56	8.31
MgO..........	5.02	4.36	5.31	5.54	5.16	5.28
Na_2O.........	5.08	7.63	7.66	5.14	7.12	6.49
K_2O...........	1.88	2.31	0.69	1.99	1.21	1.33
P_2O_5..........	0.97	0.21	.....	....	0.13	....
	99.97	100.11	98.55	98.75	99.52	98.88
Sp. gr.	2.733	2.704	2.695	2.711	2.736	2.604

results, and this mineral seems to be absent, contrary to the usual composition of hornblende basalts. That all the specimens were fresh is shown by the very small ignition loss. With the above analyses I, II, III, and VI may be compared the analyses of basalts from the Cascade Mountains, Oregon; Ferdinandea Islands; and the Ætna lavas of 1766 and 1802, as quoted by Roth.* A striking feature is the very small percentage of K_2O shown in analyses IV and V of the leucitic north and southeast streams. The leucite is seen under the microscope to be present in not very great abundance, yet a higher percentage of K_2O was expected. Zirkel† in his work on basalts describes similar cases, and remarks that it is not absolutely necessary for a leucitic basalt to be distinguished by a high K_2O percentage.

A word in regard to the specific gravities: While they are all rather low for basalt, yet this is to be explained by their very large glass content. It will have been noticed also that, with the exception of the tachylytes, whose specific gravities are curiously high, the figures show a pretty regular gradation from the least to the most glassy. For the purpose of more ready comparison the table on p. 58 is inserted. The determinations were all made with a Thoulet's solution and a Westphal's balance at 15° C.

* Roth, Beitr. z. Petrog d. pluton. Gesteine. Berlin, 1884. Dolerit und, Dolerit basalt, Nos. 11, 15, 31, and 29.

† Zirkel, Besaltgesteine, p. 191. Cf. Iddings, Origin Ign. Rocks, *l. c.* p. 166.

Variety.	Specific Gravities.	Average.
Normal basalts....................	2 813, 2.733, 2.721	2.756
Hyalopilitic basalts (Leucitic).......	2.736, 2.715, 2.712, 2.711	2.719
Hyalopilitic " (Leucite-free)..	2.704, 2.647, 2.613	2.655
Semi-vitreous "	2.604	2.604
Tachylytes.......................	2.747, 2.695	2.721

General Conclusions.—Having now described the Kula basalts it remains for us to make a few general remarks on them:

That they form a good example of a "petrographical province," as before spoken of, the reader will now see for himself, but, of course, this fact comes out more clearly from a microscopic examination of the rocks themselves than from any description. The most striking feature about them is the unfailing presence of basaltic hornblende, and its peculiar alteration products. As stated before, the hornblende, as regards constancy, invariability, and quantity, surpasses the augite, olivine, or feldspar, and here plays the leading rôle, and not a subsidiary one as in other hornblende-bearing basalts. So much so is this the case, that here I feel justified in grouping the Kula and similar basalts together as a sub-group, and giving them a separate name, although thinking that a too free use of new names is rather a hindrance than a help to science. The name which first suggests itself, and which on consideration seems most appropriate, is *Kulaite*. By this we understand a sub-group of the basalts—either plagioclase-, nepheline-, or leucite-,—which is characterized by the invariable presence of hornblende as an essential constituent, which also, both in quantity and invariability, surpasses the augite; in other words, to a large extent replaces the latter. We can have the further subdivisions of leucite-kulaite, and nepheline-kulaite.

The gradual transition shown from the least to the most crystalline, and the constancy of the chemical composition in all of them, are also interesting. The leucite-kulaites seem, however, to have been among the last poured out by Kula Devlit, though from Kara Tepé, a very short distance off, came at a probably later date a leucite-free kulaite. The whole region must, however, be more carefully examined before entering into a discussion of this and other points. The writer therefore defers further remarks and the bringing up of other points till after an exploration of the region in the spring of 1894, which he hopes to accomplish.

ENCLOSURES.*

But besides the kulaites we must describe the quite numerous enclosures of foreign minerals and rock which were found in them. These fall under two heads:

1st. Generally small enclosures, chiefly of quartz and plagioclase, which show signs of great alteration, and are rather intimately associated with the basalt, perhaps endogenous enclosures.

2d. Masses of foreign rock which have to a large extent preserved their original form and structure, and which do not show intimate association with the kulaite,—exogenous enclosures.

These two groups represent different original rocks, and are in no way connected with one another.

Endogenous (?) *Enclosures.*—These all have rounded outlines, and many have been melted after being enclosed in the stream. The majority of them are quartz and plagioclase, but enclosures of orthoclase and a fibrous mineral were also seen. Enclosures of one or the other of these kinds were found in specimens from all the streams, except those of the second period. As fewer specimens of these were collected, it is possible that they will also be found here on further search. About twenty were to be found in the slides, and about a dozen were seen megascopically.

Quartz Enclosures.—These are quite numerous, and most of the megascopically visible enclosures belong here. One of them measures 15 mm. long. They are perfectly clear, colorless or with a tinge of yellow, rounded in shape, and much cracked.

Under the microscope they show the usual features of quartz enclosures in eruptive rocks. They are clear, somewhat cracked, and are frequently melted to a colorless or rarely light-brown glass. Occasionally a kernel of unmelted quartz remains in the centre, but most of them are completely melted. The glass has the usual fringe of greenish augite needles round the edge, all of them pointing radially inward. The extinction-angle of these microlites is about 40°. One such enclosure contained inclusions of many small

* As a distinction seems advisable between essential mineral components of a rock which are included in larger crystals, and fragments of foreign bodies—either altered or not—which have become enclosed in the lava stream during its flow, I use throughout this paper the words "*inclusion*" for the former case and "*enclosure*" for the latter.

(0.005-0.01 mm.), sharply crystallized green octahedra of spinel. Another—completely vitrified and with large augite microlites—was seen as an inclusion in a large augite crystal.

Plagioclase Enclosures.—These are also numerous and quite large, some reaching a diameter of 4 or 5 mm., when they can be readily distinguished without the lense. Under the microscope they appear as colorless masses of irregular outline. They all show twinning lamellæ, and two of these which had nearly symmetrical extinction gave angles of 7° 30′ and 8° 10′, corresponding to labradorite of about the composition Ab_3An_5. In some cases these plagioclase masses have apparently been melted, as one or two were seen containing crystals of hornblende exactly similar in size, color, and stage of alteration reached to the neighboring ones in the kulaite. Others, again, show at the edges a narrow border of secondary feldspar crystals arranged radially. Here the periphery of the plagioclase enclosure has evidently been melted, and has recrystallized in a new form in accordance with its changed conditions. This fusion may have taken place at the moment of solidification, when a rise in temperature took place. Several of them contain apatite in short colorless or bluish-gray prisms, often with dusty inclusions.

In addition to the hornblende and apatite most of these enclosures include several minerals of secondary origin, their formation being due to the metamorphic action of the molten basalt. These secondary minerals are dark olive-green spinels, which are very common, sillimanite needles, and biotite. One plagioclase enclosure deserves especial description on account of the number and variety of its secondary inclusions. This was in a specimen from the latest southeast stream, and consists of a clear mass of plagioclase showing very few twinning lamellæ. Green spinels are scattered through it, but are chiefly clustered together in a long streak. Near this is a group of small violet-gray isotropic crystals of perofskite. Through a great part of the feldspar runs a stream of sillimanite needles, lying parallel to one another and the direction of the streak. A few irregularly shaped brown biotite flakes are scattered through the mass, and in one corner are seen two or three glass inclusions of probably secondary origin, consisting of a ring of very pale-brown glass (0.02 mm. in diameter) with a bubble in the centre.

Orthoclase and Fibrous Enclosures.—Of the former only two were seen. They are rounded in outline, and the feldspar is mostly clear, but is cloudy and opaque on the edges and along cracks. Several small rounded masses of colorless fibres were observed, which show aggregate polarization. What this mineral is could not be determined, but it is neither sillimanite nor zoisite. In one case a few brown spinels were included, and some clear light-brown glass was seen between the fibres.

These enclosures may represent a primary separation of some constituents of the magma, though the habit of the quartz grains points rather to exogenous enclosures. In this latter case the original rock would have been a quartz diorite. No such rock is mentioned by Tchihatcheff as occurring in the vicinity, and none was seen by me. For occurrences of quartz in basalt see note.*

Exogenous Enclosures.—Several cases were seen of fragments of foreign rock enclosed in the lava, and of these three specimens were brought back for examination. One comes from the west inner wall of the Kula Devlit crater, and the other two from blocks in the latest southeast stream. Though the last two are much decomposed by the action of the atmosphere, they all seem to be fragments of the same original rock, and we shall describe the crater specimen as the typical and best-preserved example.

Macroscopically this is a fine-grained compact rock, of general grayish color, though on closer examination it is seen to be made up of white, greenish-gray, and brownish grains.

Microscopically it is seen to be holocrystalline, with medium-grained granitic structure, composed chiefly of rounded xenomorphic augite, quartz, and orthoclase grains, and seems to be an augite granite.

The augite grains are colorless, but here and there colored yellowish green through chloritic decomposition. The cleavage is very well marked, the relief high, and the polarization colors the usual bluish gray and yellowish. Inclusions of small zircons were sometimes seen.

The quartz is sometimes cracked, but clear, and much of it acts as a cement for the other grains. As inclusions were seen small magnetite grains and a few glass specks, but no liquid inclusions or bubbles were noticed. A few small augites and zircons are also included.

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* Iddings, Am. J. Sci. xxxvi, 1888, 208; Bull. U. S. Geol. Survey, No. 66, 1890.

The orthoclase grains are perfectly fresh, as a rule, and present no specially interesting features. In some places it is kaolinized and cloudy. Besides the orthoclase, a few clear plagioclase grains were seen, distinguishable by their twinning lamellæ.

In addition to the above, zircon and iron ores are present. The former is in small hair brown crystals, some showing the bi-pyramid $x(311)$. The pleochroism is very distinct, being colorless, or of a very faint greenish tinge parallel to $\acute{c}$, and dark brown parallel to a. The ores are magnetite and ilmenite, the latter being distinguished by the mantle of leucoxene. They form irregular black grains and show the lustre very distinctly.

In one place in the slide is seen a fissure filled with colorless glass which contains some zircons and is much cracked.

The rock on the whole shows extremely few signs of alteration due to the action of the basalt. The weathered specimens have been altered to masses of calcite and kaolin, with here and there augite and quartz grains. Some spots of extremely pale brown glass with a network of fine veins of colorless glass running through them were seen in these specimens.

Like the diorite no such rock is known in the vicinity as a surface occurrence, but to judge from the slight alteration it has undergone both in form and structure, it is probable that this rock lies quite close to the surface.

On further consideration it has occurred to me that R. Mallet's theory of the origin of volcanic energy may explain the difference in the state of alteration of the two kinds of enclosures on the supposition that the so-called "endogenous" enclosures are in reality exogenous. Mallet* ascribes the heat shown in volcanic phenomena to pressure between two parts of the earth's crust, caused by tangential strains consequent on the contraction of the crust during the earth's secular cooling. He shows that this heat would be most developed along cracks or other lines of weakness, and further that the heat would be greater the greater the resistance to pressure; for instance, the crushing of a granite evolving much more heat than that of a sand-stone. He further shows that sufficient heat is developed by the secular cooling of the globe to much more than account, with the presence of water at the point of origin, for all the volcanic phenomena observed. Here, it seems to me, we have

* R. Mallet, On Volcanic Energy. Phil. Trans. 1873, 147.

a possible explanation of the greatly altered and disintegrated condition of the so-called "endogenous" enclosures, they being remains of the rock which was crushed and melted at or near the point of greatest pressure, where, on the entrance of water, the eruption was started. They would hence have been subjected to peculiar conditions, entirely different from the "exogenous" enclosures, which may be supposed to come from the walls of the conduit, fragments caught in the lava stream during its ascent. The above idea is put forward as a possibility, and no stress is laid upon it.

Miscellaneous Rocks.

Besides the lavas of the region some other rocks were collected and may now be briefly described.

Mica Schist.—This was obtained from the foot-hills to the west of Kula, and is an ordinary yellowish-gray, glistening foliated schist.

Under the microscope it is seen to be composed almost entirely of muscovite flakes, with some orthoclase between the crystals acting as cement, and in grains, and a few zircons and quartz grains. Several long greenish-gray tourmalines were also seen. It calls for no further remark.

Hornblende Schist.—The specimen was obtained from near Azi Köi, about an hour and a half from Ala Shehir, on the south slope of the Konurja Mountains. It is a very fine-grained, compact rock, banded in structure, the bands being alternately dark green and white.

Under the microscope the white bands are seen to be composed of many rounded orthoclase and some quartz grains, a few plagioclase grains with twinning lamellæ, and many small colorless zircons which are arranged parallel to the banded structure. Small flakes of brown biotite are also met with.

The dark bands, on the other hand, show an abundance of dark grayish-green hornblende grains, mixed with the orthoclase grains. These are strongly pleochroic as follows: $\mathfrak{c}$ = dark grayish green ; $\mathfrak{b}$ = yellowish green ; $\mathfrak{a}$ = pale greenish gray. These grains are arranged with their $\dot{c}$ axes parallel to the bands. Some of them are of a blue color, and may be referred to glaucophane. Small zircons abound and some colorless garnets, generally arranged in clusters and often showing crystallographic planes, are present. The biotite flakes are also not wanting, but they are scarce.

Diabase.—About fifteen minutes below the first Turkish guard-house on the southern slope of the Konurja Mts. was found a dike about 5 metres wide in the schist. The rock is of a dark greenish color, very fine grained and compact. Some crystals of brown diallage and white feldspar are to be seen.

Under the microscope the rock seems to be a much-altered diabase, containing diallage, and shows the following composition: The structure was originally rather porphyritic, and what was the groundmass and augite has now become a mass of pale grayish green, slightly pleochroic hornblende grains, grouped irregularly and bedded in a mass of feldspar, most of which is plagioclase, but of which some is orthoclase. In the hornblende clusters are large irregular grains of magnetite, and through all this groundmass are scattered needles of apatite and clusters of colorless garnets. A few brown biotite flakes are also present.

The porphyritical crystals of feldspar, while preserving their form fairly well, have suffered much alteration; being filled with a felt of sillimanite needles, which is especially thick towards the centre. Between the needles are many grains of zoisite showing a fine blue polarization color. Biotite flakes and a few small magnetic grains are included.

The diallage occurs in crystals from 2–4 mm. long of a gray-brown color. They are frequently filled with thick, dust-like inclusions, and some show a dark-brown core, then a lighter zone, and at the outside a dark-gray border filled with "dust." One crystal has as an inclusion a large unaltered plagioclase crystal. The extinction angle in one case was 30°. The crystals are generally surrounded by a ring or border of green hornblende grains.

This diallage seems to be about the only mineral which has not undergone profound alteration and is not secondary—the hornblende, sillimanite, zoisite, biotite, magnetite, and probably the garnet and some of the feldspar being of secondary origin. The completeness of the change is striking—the augite having completely disappeared, and being changed into the masses of granular hornblende, and the feldspar undergoing an alteration similar to saussuritization, though with less loss of form. The rock reminds one of an altered diabase from Assuan, in Egypt, where also the augite has been changed into the same green granular hornblende, with some uralite, and the feldspar to zoisite, but no sillimanite.

Serpentine.—A narrow vein of light green serpentine was found in the limestone near the end of the north stream. It offers, however, no special features of interest, showing under the microscope a mass of colorless or pale green serpentine fibres, with a few magnetite grains. No olivine was seen.

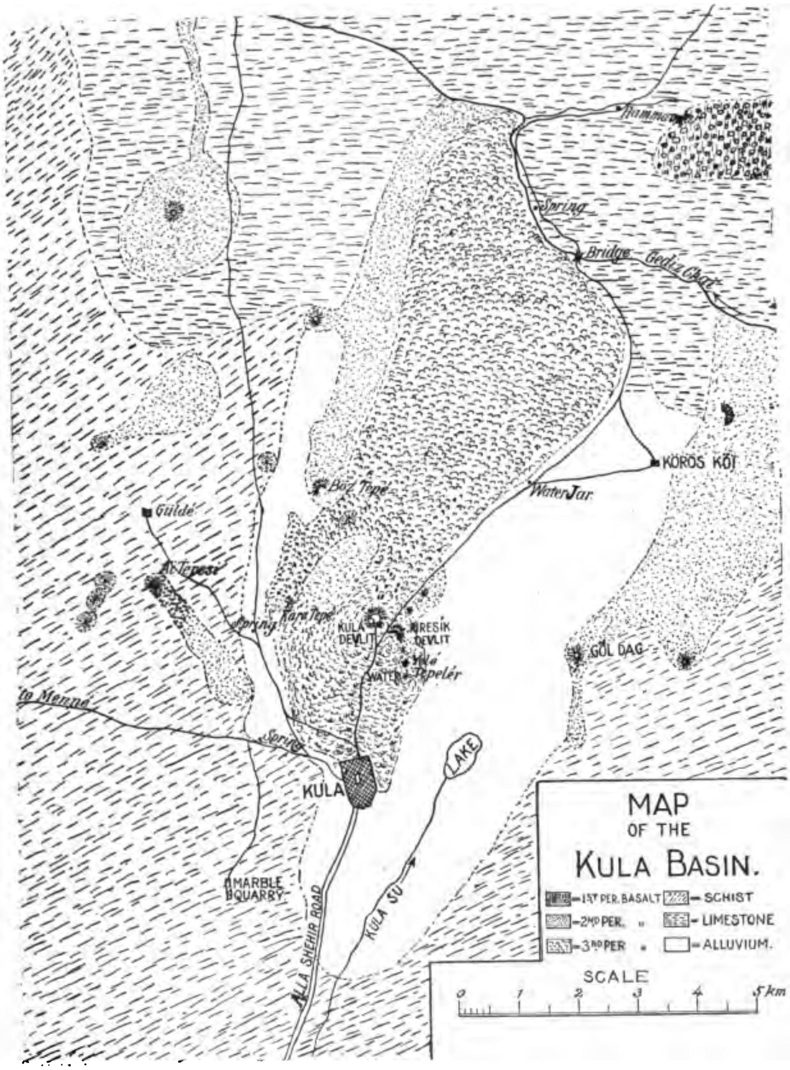
VITA.

I, Henry Stephens Washington, was born on January 15, 1867, in Newark, New Jersey, United States of America, my parents being George Washington and Eleanor Washington (*née* Stephens). After due preparation at home and at school I entered Yale College (now University) at New Haven, Conn., from which, at the end of the regular four years' course, I graduated, with a special honor in Natural Sciences, as B. A. in 1886. I spent the following two years in study at Yale University, during which I held for a year the Silliman Fellowship in Physics, and took the degree of M.A. in June 1888. The next four years were spent chiefly in travelling in the West Indies, Europe, Egypt, Algeria, Asia Minor, etc., parts of four winters and springs being passed in Greece, where I became a member of the American School of Classical Studies, and assisted in and conducted excavations in Attica and at Platæa, Argos, and Phlius. The winter semesters of 1891–92 and 1892–93 I passed at Leipzig, studying at the University.

In Yale College and University I studied under Professors J. D. Dana, Brush, E. S. Dana, A. W. Wright, Newton, Wells, Penfield, and numerous others. In Athens I heard the lectures of Drs. Waldstein and Dörpfeld, and Profs. Gardiner and Tarbell. In Leipzig I have attended the lectures of Professors Overbeck, Zirkel, Wiedemann, Credner, Schreiber, and Lenk.

To all these teachers of mine I owe the greatest thanks, but above all to Professor E. S. Dana of New Haven, under whom for three years I studied mineralogy and petrography, and to Geheimrath Bergrath Prof. Dr. Zirkel, under whose direction this paper was written and for whose friendly counsel and aid I feel deeply grateful.

PLATE I.



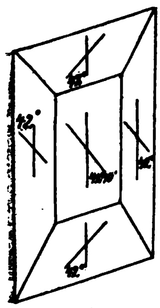
Spring
Bridge
Gediz Chai
KOROS KÖI
Water Jar
Boz Tepe
Gülde
Kara Tepe
Spring
KULA DEVLIT
KRESIK DEVLIT
Tepeler
WATER
GÖL DAG
to Menne
Spring
KULA
LAKE
MARBLE QUARRY
ALLA SHEHIR ROAD
KULA SU
MAP
OF THE
KULA BASIN.
=1ST PER. BASALT
=2ND PER. "
=3RD PER "
=SCHIST
=LIMESTONE
=ALLUVIUM.
SCALE
0 1 2 3 4 5 km

PLATE II.

FIG. 1.—KULA DEVLIT FROM THE S. W.; PIRESIK DEVLIT ON RIGHT.

FIG 2.—"KNOLL" WITH LAVA STREAM, S. E. OF KULA DEVLIT.

PLATE III.



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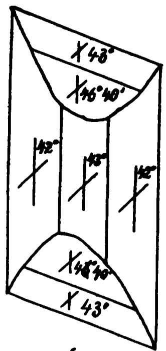

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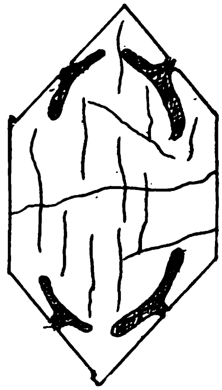

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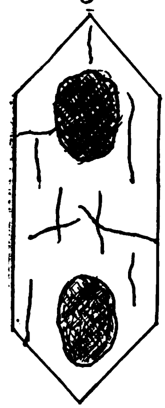

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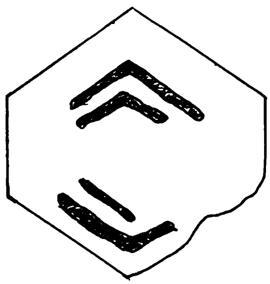

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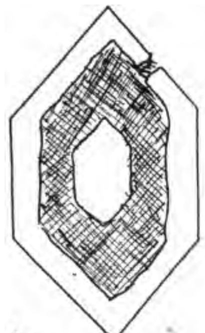

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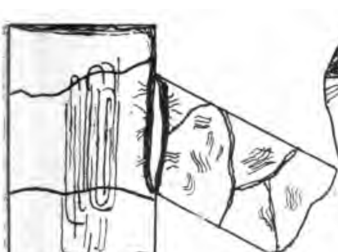

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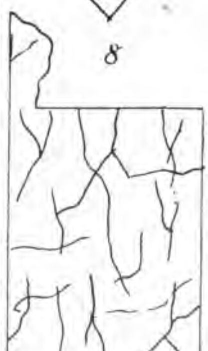

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PLATE IV.

FIG. 1.—FROM S. W STREAM, SHOWING HORNBLENDE PARTIALLY ALTERED TO BROWN AGGREGATE.

FIG. 2.—FROM SECOND PERIOD STREAM (WELL DIGGING), SHOWING HORNBLENDE COMPLETELY ALTERED TO AUGITE OPACITE AGGREGATE.

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